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NUTRIENT MANAGEMENT VOLUME II: REMOVAL TECHNOLOGY PERFORMANCE & RELIABILITY

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ABSTRACT AND BENEFITS

Abstract:

The Water Environment Federation (WEF) and the Water Environment Research Foundation (WERF) cooperated in a comprehensive study of nutrient removal plants designed and operated to meet very low effluent TN (total nitrogen) and TP (total phosphorus) concentrations, several as low as 3.0 mg/L TN and 0.1 mg/L TP. The investigation also focused on the ability of nitrification technologies to meet low maximum daily limits for ammonia. This effort focused on maximizing what can be learned from existing technologies in order to provide a database that will inform key decision makers about proper choices for both technologies and rationale bases for statistical permit writing. Managers of 22 plants provided three years of operational data that were analyzed using a consistent statistical approach that considered both process reliability and the permit limits applied. A proposed set of quantitative descriptors were developed to describe the performance of BNR (biological nutrient removal) plants meeting stringent nutrient requirements in terms of effluent quality percentile statistics. Technology Performance Statistics (TPS) were defined as three separate values representing the ideal, median, and reliably achievable performance. Also, monthly average 95th percentiles of effluent data were used to compare the 22 plants in terms of their ability to achieve the 3.0 mg/L TN or 0.1 mg/L TP criteria. Maximum daily statistics were used to stratify the ability of plants to meet low maximum daily permit levels.

Benefits:

- Focuses on maximizing what can be learned from existing nutrient removal and nitrification technologies in order to provide a database that will inform key decision makers on proper choices about these nutrient removal processes and provide a practical and consistent statistical approach to permit writing.
- Establishes a new protocol for the analysis of nutrient removal and nitrification plants striving to achieve low effluent concentrations.

Keywords: Nutrient removal, nitrification, statistical reliability, permitting, nitrogen removal, phosphorus removal, limit of technology.

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AADF	Annual average daily flow
AS	Activated sludge
AO	Administrative Order
AWT	Advanced wastewater treatment
AWTF	Advanced wastewater treatment facility
AWWTP	Advanced wastewater treatment plant
BAF	Biologically active filter
Bio-P	Enhanced biological phosphorus removal
BFP	Belt filter press
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
cBOD	Carbonaceous biochemical oxygen demand
BR	Biofilm reactor
CCT	Chlorine contact tank
CEPT	Chemically Enhanced Primary Treatment
COD	Chemical oxygen demand
COR	Coefficient of reliability
CoV	Coefficient of variance
CWA	Clean Water Act
DAFT	Dissolved air flotation thickener
DMR	Discharge monitoring report
DNAS	Denitrifying activated sludge
DO	Dissolved oxygen
EWRF	Orange County Utilities Eastern Water Reclamation Facility
EBPR	Enhanced biological phosphorus removal
EPD	Georgia Environmental Protection Division
FAT	Final acceptance test
FDEP	Florida Department of Environmental Protection
GAC	Granular Activated Carbon
HPOS	High purity oxygen system
HRAS	High rate activated sludge
HRT	Hydraulic retention time
I/I	Infiltration/Inflow
LAS	Land application system
LOT	Limit of technology
MADEP	Massachusetts Department of Environmental Protection

MBR	Membrane bioreactor
MDL	Minimum detection limit
MLD	Million liters per day
MLE	Modified Ludzak-Ettinger
MGD	Million gallons per day
ML	Mixed liquor
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
m-UCT	modified University of Cape Town
N	Nitrogen
NAS	Nitrifying activated sludge
nbDON	Non-biodegradable dissolved organic nitrogen
NH_3	Ammonia
NH_3-N	Total ammonia and ammonium as nitrogen
NO_2	Nitrite
NO_3	Nitrate
NO_X	Nitrate and nitrite
NPDES	National pollutant discharge elimination system
NTF	Nitrifying trickling filter
ON	Organic nitrogen
OP	Ortho-phosphate
ORP	Oxidation reduction potential
P	Phosphorus
POTW	Publicly owned treatment works
RAS	Return activated sludge
rbCOD	Readily biodegradable chemical oxygen demand
RI	Rapid infiltration
SAT	Soil aquifer treatment
SCT	Solids contact tank
SCADA	Supervisory control and data acquisition
SFB	Sand filtration beds
SRT	Solids retention time
TDS	Total dissolved solids
TF	Trickling filter
TF/SC	Trickling filter/solids contact
TFT	Thickened feed tank
TIN	Total inorganic nitrogen
TMDL	Total mass daily load
TN	Total nitrogen

TP	Total phosphorus
TPS	Technology performance statistic
TSS	Total suspended solids
T-TSA	Tahoe-Truckee Sanitation Agency, CA
U.S. EPA	United States Environmental Protection Agency
UV	Ultraviolet
VFA	Volatile fatty acid
VFD	Variable frequency drive
VSS	Volatile suspended solids
WAS	Waste activated sludge
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WRC	Water reclamation center
WRD	Water reclamation district
WRF	Water reclamation facility
WWTF	Wastewater treatment facility
WWTP	Wastewater treatment plant

EXECUTIVE SUMMARY

ES.1 Introduction

WERF funded a two-year comprehensive study of nutrient removal plants designed and operated to meet very low effluent total nitrogen (TN) and total phosphorus (TP) concentrations. Both existing and new technologies are being adapted to meet requirements that are as low as 3.0 mg/L TN and 0.1 mg/L TP, and there is a need to define their capabilities and reliabilities in the real world situation of wastewater treatment plants. A concern over very low maximum daily permit limits for ammonia caused the work to be extended to include nitrification reliability. This effort focused on maximizing what can be learned from existing technologies in order to provide a database that will inform key decision makers on proper choices about these nutrient removal processes and provide a practical and consistent statistical approach to permit writing. To this end, managers of 22 plants, 10 achieving low effluent TP, nine achieving low effluent TN, and three achieving low effluent NH_3-N, provided three years of operational data that were analyzed using a consistent statistical approach. Technical papers were compiled for each plant including a summary of influent loading, process design and operating conditions, unusual events, upsets, and anecdotes related to process operation, and the statistical summary of final effluent data that considered both process reliability and the permit limits applied. This effort culminated in workshops held at WEFTEC 2008 and WEFTEC 2009. Technological conclusions can be drawn from the study in terms of what can be learned by comparing the different nutrient removal and nitrification processes employed at these 22 plants. In a parallel effort, using the data and conclusions generated from this study, a proposed set of quantitative descriptors were developed to describe the performance of treatment plants meeting stringent nutrient or nitrification requirements in terms of effluent quality percentile statistics. Technology Performance Statistics (TPS) were defined as three separate values representing the ideal, median, and reliably achievable performance.

ES.2 Methodology

A relatively simple statistical technique can be used to analyze treatment plant data to determine the reliability of nutrient removal process performance. Using percentiles calculated from final effluent data, the performance of the process and its associated reliability and variability can be quantified. TPS values representing the ideal performance (TPS-14d), median TPS (50%), and reliable TPS (typically 95th percentile based on either daily or monthly data) values provide plant owners, plant designers and regulators a tool to determine the ability of a technology or process to meet permit limits under consideration. Reliability of plants accomplishing nitrification was also examined, with a principal focus being the reliability of meeting maximum day permits for total ammonia nitrogen.

ES.3 Results

Using the data reported by the full-scale facilities analyzed in this study, the project showed that:

- The lowest 14-day per year performance (3.84th percentile or rank) represents the ideal TPS value. This provides an unbiased value of the ideal performance of the technology when it is minimally influenced by all the factors that cause statistical variability in real plants. This is indicated by the TPS-14d value. The median value provides a statistical assessment of expected performance on an annual basis and provides a means for quantifying process variability when compared to other TPS values. The reliable performance is typically based on the 95^{th} percentile, a typical measure of maximum month performance, but this selection depends on the risk tolerance of the utility, as this value would also represent three exceedances of a monthly permit limit in a typical five-year permit cycle.

- The operating conditions and specific conditions under which the data were collected impacts the TPS values. Permit or target treatment goals, external factors such as wet weather or industrial discharges, and internal factors such as construction, impact the variability of the results. All data should be included in the analysis. If special circumstances exist to exclude some data, the exclusions should be clearly stated.
- Flowsheets have been identified that have achieved either a monthly max of 3.0 mg/L TN or 0.1 mg/L TP on a 95^{th} percentile basis. It is important to recognize that performance at this level for both TN and TP at the same plant has not been demonstrated.
- Separate stage N removal plants outperform combined N removal plants seemingly due to a higher degree of denitrification control possible with a separate stage process.
- Four- or five-stage Bardenpho plants come close to meeting the monthly TN goal of 3.0 mg/L, 95% of the time; a prior survey of 10 plants in a warm climate (Florida) show a capability of 3.5 mg/L. The exemplary performance of the cold climate Kalkaska plant, even though it only monitors total inorganic nitrogen (TIN), shows that it may reach close to 3.0 mg/L TN on 95^{th} percentile monthly basis, when assuming a range of values for its (unmeasured) ON content.
- As a class, single stage chemical addition processes for TP removal outperformed multiple stage processes, but often at the expense of higher chemical dosages.
- Tertiary chemical addition and effective filtration (gravity, media, or membrane) is required to achieve very low P. Plants with some form of tertiary chemical addition, clarification, and filtration outperform (slightly) those which have only effluent filters.
- The status of performance with membrane bioreactors (MBRs) for either N or P removal cannot be resolved (limited plants with three years of data).
- Kelowna and Kalispell (single stage BioP plants) performed very well without tertiary chemicals achieving 0.10 and 0.15 mg/L on median daily basis. This represents a tremendous achievement in terms of weaning plants from chemicals.
- Full-scale plant performance for total nitrogen showed that the TPS-14d value of a typical plant is 50-60% of the median value. The TPS-95% is 180-250% of the median value. This clearly demonstrates the substantial variability in effluent quality even for a selection of the best performing nutrient removal plants in the U.S.
- Full-scale plant performance for total phosphorus showed that the TPS-14d value of a typical plant is 40-50% of the median value. The TPS-95% is 200-300% of the median value. Again, a significant degree of variability in performance was observed.
- 95^{th} percentile values for maximum month performance should not be the basis of regulation, since they represent three months of permit exceedance in a five-year permit period. For several plants, the maximum month value was significantly higher than the 95^{th} percentile value and no consistent relationship between the two statistics was found.

- Only four plants were identified that could meet a maximum daily effluent ammonia limit of 4.0 mg/L, meaning that reliability of plants with limits less than 4.0 mg/L will be expected to be poor. Other measures beyond what has been provided in the exemplary plants examined will have to be implemented to meet low maximum daily ammonia limits.

ES.4 Discussion

Many factors that influence reliability and variability were determined from the data and from the plant managers. These included external and operations or design influences as follows:

- Infrequent toxic event upsets. Biological processes are a main feature of all the plants surveyed and are subject to upsets.
- Unexpected interruptions in chemical supply. The majority of plants in the survey use chemicals for either nitrogen or phosphorus removal.
- Plant upgrading projects and the impacts of construction on effluent reliability.
- Peak flow events were the most difficult operating issues along with seasonal variations in flows and loads.
- Biological treatment capacity issues impacted performance during more stressed periods.
- Internal sludge supernatant recycle streams containing ammonia.
- Chemical feed control issues for phosphorus removal.
- Fermenter control issues were the most difficult aspect of operations in plants reliant solely on biological phosphorus removal.

ES.5 Conclusions

A major finding of the WEF/WERF investigation was that statistical variability is a characteristic of all the exemplary plants and that this variability should be recognized in both evaluation of technologies (e.g., stratifying them in terms of their capabilities) in an engineering environment as well as determining the appropriate effluent limits in the regulatory permit setting environment.

Although water quality protection must be the focus of point source nutrient permitting efforts, nearly all discharge permits applied to treatment plants in the U.S. require near 100% reliability; the consequence of not achieving this level of reliability is a permit exceedance. Based on this study of 22 plants approaching very low effluent concentrations, deterministic permit limits may not be appropriate for plants achieving very low nutrient limits, particularly when the limit is based on technology (concentration) rather than water quality-based (load). In addition, long averaging periods (i.e., annual average) are warranted given the inherent increase in variability of processes that must remove N and P species to concentrations approaching zero.

Local conditions impact the performance achieved on average and in terms of statistical variability. These factors include process design, climate impacts, wet weather flow influences, attributes of the service area, variation in influent flows and loadings, presence or absence of industrial contributions, whether solids processing is accomplished on the same site, sustained or interrupted supplies of chemicals, construction impacts, mechanical failures, the difficulty in operating the process, the ability to automate the controls of a process, the closeness of operation to design flows and loadings and others. This makes it inadvisable to directly translate either the average performance or the statistical variability directly from a known plant situation to another location where there is no supporting database (for example, for a plant converting from secondary treatment to nitrification or nitrogen removal).

No clear relationship between flow and loading and performance could be deduced, except for clearly overloaded plants, such as EWRF. However, it should be expected that performance would suffer at a plant that is continually overloaded. River Oaks and ASA were overloaded on some parameters but were amongst the best performers in the study. There are many factors that impact this, such as the conservatism built into the design. Most of the plants in this study were underloaded with respect to flow and load.

Despite the various factors influencing performance from site to site, four plants out of the 22 plants analyzed in this study have been identified as the best performing plants with respect to nitrogen removal when evaluated on a maximum month basis. These are the Fiesta Village, River Oaks, Truckee Meadows, and the Western Branch plants. Their 95th percentile monthly performance varied only from 2.2 to 2.5 mg/L TN. Considering all the factors influencing their performance, they cannot be further distinguished, in a technology stratification sense, one from the other. Their superior performance has one thing in common: they have either a separate denitrification stage or a polishing step with methanol, which allows more precise control of effluent quality than the processes with combined flow sheets (like Bardenpho) offer. This is not to say that any plant with one of the flowsheets these four plants represent can be placed anywhere, under any climatic and flow and loading condition and be expected to produce the same result. The four plants exhibit significant effluent TN variability in Technology Performance Statistics (concentrations and performance ratios), as documented in this report.

As another example, this investigation has shown that at low effluent TN levels, the composition of the TN becomes dominated by organic nitrogen (ON) that is resistant to further biological degradation. The ON residual is known to have significant plant to plant variability and is impacted by industrial contributions specific to each plant, ON in the drinking water supply, as well as by extracellular production of ON by the biological organisms in the wastewater treatment process. Understanding the composition of ON and designing processes that can effectively remove it is a research need, if even lower effluent TN levels are sought beyond the capabilities of the technologies examined in this investigation.

It is the obligation of the regulators, regulated community, and design engineering profession to recognize the higher risks and the process variability that are attendant with the design for very low nitrogen and phosphorus concentrations or very low maximum day ammonia concentrations. When designing for typical secondary treatment requirements, high effluent concentration days can be balanced against low effluent concentration days. When designing for concentrations close to zero, it would require negative concentrations (which do not exist) to provide similar risk mitigation as occurred in the past with conventional secondary treatment. With current technologies, when designing or operating for very low levels, it is possible for regulators to permit concentrations that will automatically result in effluent exceedances no matter how much effort and cost is expended. The goal for regulators, operators, and plant designers should be to assure the public that the investment of public dollars can properly be done by finding statistical bases for regulation that are both protective of the environment and are technologically achievable.

Considerable judgment must be employed in using this information in designing for greenfield plants or conversions of secondary processes to nutrient removal, as the database herein can only be used for guidance and cannot be directly be translated. In design, highly parameterized plant process models are routinely used. When designing for effluents close to zero, these models do not accurately capture the statistical variability of nutrient removal processes. For such situations there are many unknowns that are not resolvable early in project implementation and are only partially compensated by conservatism in design. In such cases, success will only be statistically defined in the first years of plant operation.

This investigation was limited by the availability of exemplary performing plants that had been operating for at least 36 months. In future years, the technologies that were emerging at the time of writing will have come on line and should be subject to evaluation. In addition, there were a very limited number of nitrogen removal plants operating in cold climates in either the combined or multiple stage configurations at the time of study. However, there are a number of these currently under construction and data will start to become available within four or five years. Other technologies, such as biologically active filters (BAFs) and MBRs configured for either low nutrient concentration or high degrees of nitrification will be coming on line and can be used to extend the database assembled in this investigation. When these plants accumulate sufficient operating history, they should be subjected to analysis so as to expand the conclusions about technology stratification presented herein.

Many technical publications can be found in the literature making claims about the capabilities of specific technologies in reaching low nutrient concentrations. Unless supported by complete descriptions about plant operation and design, along with statistical analysis of data from longer term operating periods, these claims should be viewed with a high degree of skepticism. As can be demonstrated by examination of almost any of the cases analyzed here in, presentation of performance data without stating its statistical characteristics is virtually meaningless. Indeed, this investigation establishes a new protocol that should be used for data presentation in the future, so that data between studies can be comprehensively compared on common bases.

CHAPTER 1.0

PROJECT BACKGROUND AND OBJECTIVES

1.1 Introduction

The WERF Nutrient Challenge research program and WEF cooperated in a comprehensive study of nutrient removal plants designed and operated to meet very low levels of effluent nitrogen and phosphorus. Both existing and new technologies are being adapted to meet requirements that are as low as 3.0 mg/L TN and 0.1 mg/L TP, and there is a need to define their capabilities and reliabilities in the real world situation of wastewater treatment plants. This effort focuses on maximizing what can be learned from existing technologies in order to provide a database that will inform key decision makers about proper choices for both technologies and rationale bases for statistical permit writing. To this end, managers of 22 plants, 10 achieving low effluent TP, nine achieving low effluent TN, and three achieving low effluent ammonia, provided three years of operational data that were analyzed using a consistent statistical approach. Technical papers were compiled by a manager representing each plant included a summary of influent loading, process design and operating conditions, unusual events, upsets and anecdotes related to process operation, and the statistical summary of final effluent data that considered both process reliability and the permit limits applied.

1.2 Project Background

Two similar studies impacted the direction of this investigation. The first was a survey of Florida nutrient removal plants completed by Brown and Caldwell (Jimenez et al., 2007). The study found it useful to analyze 36 months of data in order to better define the probability of attainment of maximum month effluent requirements, rather than a more typical 12 months of data. The Florida survey focus was most useful for defining the performance capabilities of nitrogen removal plants in warm climatic conditions, so in this investigation only a few Florida plants were included and the emphasis was on nitrogen plants in moderate to colder climates. The Florida survey results were used to confirm and extend the technology rankings.

The second investigation influencing this investigation was the U.S. Environmental Protection Agency (U.S. EPA) report titled *Municipal Nutrient Removal Technologies Reference Document* which was published in 2008. It was intended to provide information that will assist local decision makers and regional and state regulators plan cost-effective nutrient removal projects for municipal wastewater treatment facilities (Kang et al., 2008). This technical report includes a statistical evaluation of 40 treatment alternatives and 30 full-scale treatment facilities all achieving some level of nutrient removal. The U.S. EPA report assisted the team in identifying plants for more comprehensive evaluation.

The U.S. EPA report determined the variability and reliability of a data set using the mean, standard deviation, and coefficient of variance (CoV). The statistical evaluation also included the 50^{th}, 92^{nd}, 98^{th}, and 99.7^{th} percentiles of each data set. U.S. EPA has indicated that these percentiles represent the annual average, max month, max week, and max day, respectively (Kang et al., 2008). The 50^{th} percentile is in fact the median value; however, its usefulness to represent the average value was not evaluated during this investigation. The statistical analyses in the U.S. EPA report could not be used directly since they were limited to a single year of data, rather than the 36-month data period chosen for the WEF/WERF investigation.

1.2.1 Plant Data

Similar analyses of nutrient removal performance have been restricted to only monthly "DMR-reported" data (Morales et al., 1991; Tetreault et al., 1989; Jimenez et al., 2007). The disadvantage of this approach is that effluent permits may possibly be set on other bases such as annual averages or daily maximum values, and this approach may not adequately describe the treatment capability of the plant because of the inherent "loss" of data variability when considering only monthly averages. Second, description of maximum month performance is often used to illustrate the capabilities of treatment facilities. When only single calendar year data are examined (or even multiple calendar years) to determine maximum month treatment capability (Morales et al., 1991; Tetreault et al., 1989), the approach may understate or overstate performance capability of the facility, depending on how many years are picked to include in the analysis. An evaluation of Florida BNR plants using 36 months of data was able to distinguish between technologies (Jimenez et al., 2007), perhaps because the longer period consistently employed more accurately captured variability within the plants. One investigation focused on daily data rather than monthly or annual average data and was able to draw conclusions about operating conditions and process design differentiation between plants (deBarbadillo et al., 2007). Based on these prior investigations, 36 months of data was the threshold for inclusion of plants and technologies in this report.

1.2.2 Reliability

Process reliability can be defined as the ability to meet the specified requirements free from failure or the probability of adequate performance (i.e., meeting permit limit) over a specified period (e.g., five-year NPDES permit period chosen as the basis for evaluation in this investigation) (Niku et al., 1979). In terms of WWTPs, reliability is also defined as the probability of success, where failure is the probability that the effluent concentration is greater than the discharge permit limit. The concepts used to calculate and apply process reliability, specifically in terms of a simplified stochastic method for treatment plant design, were first developed and used by Niku et al. (1979), and interestingly, this material was summarized and described by Tchobanoglous et al. (2003) as one of two statistical approaches for calculating WWTP effluent concentrations to be used for process design. Moreover, Oliveira and Sperling (2008) more recently extended these methods and the fundamental validity of the approach to be used in evaluating the reliability of a set of treatment plants and processes for meeting their respective permit limits, in this case focusing on biochemical oxygen demand (BOD) and total suspended solids (TSS) removal. It appears that this current investigation represents the first application of reliability analysis concepts as originally developed by Niku et al., (1979), for nitrogen and phosphorus removal at treatment facilities striving to meet low concentrations.

It is often found that experimental data produced as a result of natural processes are log-normally distributed, exhibiting significant right/positive skew. This is because the data set is bounded on the left by zero or some other lower limit but is unconstrained on the right. Examples of processes that produce log-normally distributed data are flood magnitude, rainfall intensity and duration, drought severity, etc. Similarly, it is often found that WWTP data also follow a log-normal distribution (e.g., raw wastewater characteristics, final effluent concentrations, etc.) (Tchobanoglous et al., 2003), although there are conditions that prevent the log-normal distribution from adequately describing many of the data sets evaluated as part of this study.

Considering a wide range of treatment plants and processes, Niku et al. (1979) showed that effluent BOD and TSS data are best described by the log-normal distribution, and the equations developed below assume that the data follow a log-normal distribution. As discussed below though, it is possible to use the concepts developed by Niku et al. (1979) without relying explicitly on the equations for calculating reliability in the event that the effluent data do not follow well the log-normal distribution. In the case of treatment plant design, Niku and Schroeder (1979), defined the coefficient of reliability (COR) which is defined below:

$$\text{COR} = \frac{\text{Design Concentration } (m_x)}{\text{Permit Limit } (X_s)} \qquad (1.2\text{-}1)$$

where m_x is the mean concentration to be used for design and X_S is the discharge permit limit. Using the probability density function of the log-normal distribution and the definition of the standard normal variable (Z), Niku et al.(1979) developed an equation to estimate COR at a reliability level defined by the quantity (1-α):

$$\text{COR} = \left(\sqrt{CoV^2+1}\right)\exp\left(-Z_{1-\alpha}\sqrt{\ln\left(CoV^2+1\right)}\right) \qquad (1.2\text{-}2)$$

where CoV is the coefficient of variance for the original data set (not log-transformed), which is determined by dividing the standard deviation of the data set by the mean of the data set, and Z is the standard normal variable defined by a reliability level at (1-α). For this form of the equation to be used, one would have a target reliability (e.g., 95%) and a permit limit for design. Using the target reliability, the standard normal Z value can be determined using normal probability tables or directly using Microsoft Excel™ or other statistical software packages. In this case, the variability of the process (i.e., CoV) would either be assumed or determined based on historical data or values attributable to the process being designed. The COR would be determined, and would typically range in magnitude from zero to one, providing a reasonable estimate of the effluent concentration to be used for design and based on a target reliability. As discussed below, this target reliability could be based on the averaging time required by the permit (e.g. monthly average) and the allowable number of exceedances in a five-year permit period (e.g. one month in violation for a five-year permit period). For this example and assuming the CoV is computed from daily sampling data, this would require a reliability of 98.4% based on the calculation:

$$\text{Required Reliability} = \left(1 - \frac{30}{5(365)}\right) \times 100\% = 98.4\% \qquad (1.2\text{-}3)$$

Niku et al. (1979) also developed equations to take a data set from an operating plant with its discharge permit limit and calculate the reliability of the process for meeting the permit limit. However, the process for doing this was not well explained or considered in detail in their study, because it was not the underlying objective of the work (Niku et al., 1979). Oliveira and Sperling (2008) extended this logic to reliability estimates comparing plants and processes. Again assuming the data are log-normally distributed the standard normal Z can be determined using:

$$Z_{1-\alpha} = \frac{\ln X_s - \left[\ln m_x - 0.5\ln\left(CoV^2+1\right)\right]}{\sqrt{\ln\left(CoV^2+1\right)}} \qquad (1.2\text{-}4)$$

where m_x is the arithmetic average (mean) of the original data set (not log-transformed). The reliability value can be found from the statistic table for standard normal distribution Z based on the calculated value from Equation 1.2-4. The reliability value can also be determined in Microsoft Excel™ using the NORMDIST function.

1.2.3 Limit of Technology

What is the "Limit of Technology?" This question has been raised and answered by regulators, designers, operators, researchers, environmental advocates and others. However, in each case, the answer is based on an individual's perspective, considering his or her objectives, goals, and overt or covert agenda. For instance, a plant operator would consider the limit of technology to be the best that can be achieved by the facilities at the treatment plant, the designer as the best performance reliably achievable by implementing/adding appropriate technology, and others might perceive it as the best performance that has ever been achieved by any technology anywhere.

Economic considerations are added in some instances. The EPA regulatory framework "…require[s] application of the best available technology economically achievable for such category or class, which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants…" (CWA section 301(b), 33 U.S.C. § 1311(b)).

The "Best Available Technology" is determined from a number of factors. The Clean Water Act (CWA) requires "…consideration of the reasonableness of the relationship between the costs of attaining a reduction in effluents and the effluent reduction benefits derived, and the comparison of the cost and level of reduction of such pollutants from the discharge from publicly owned treatment works to the cost and level of reduction of such pollutants from a class or category of industrial sources, and shall take into account the age of equipment and facilities involved, the process employed, the engineering aspects of the application of various types of control techniques, process changes, non-water quality environmental impact (including energy requirements), and such other factors as the Administrator deems appropriate…" (CWA section 301(b), 33 U.S.C. § 1314(b)(4)(B)).

There is currently no formal definition of the "Limit of Technology" or LOT. This is appropriate since the factors that limit the performance of a technology are dependent on the type of technology, environmental factors, engineering and operational conditions, and a host of other factors.

The term “Limit of Technology” is typically used to convey the lowest possible concentration to which a compound of interest can be reduced using a particular technique. In its broadest sense, the term is applied to convey the lowest achievable concentration using any technology. The deficiency with this approach is that the definition is not robust and is subject to the interpretation of the analyst. Therefore, this study does not use this term to define the capability of a process or technology, nor does it attempt to define LOT.

1.3 Objectives

The objective of this report is to:

- Determine to what extent existing technologies can reliably achieve low effluent values with respect to total nitrogen or total phosphorus.
- Describe the common statistical methods employed to analyze final effluent data from each treatment plant. Describe the methods developed for this project for computing process reliability as originally developed by Niku and Schroeder (1979), and as recently applied by Oliviera and Sperling (2008) for conventional pollutants to the case of plants achieving low nitrogen and phosphorus effluent values.
- Describe the development and computation of Technology Performance Statistics and their use to compare plant performance and variability.
- Compare the statistical reliability achieved by the 22 plants surveyed, considering for each the permit limit applied, log-transformed normal probability plots. Evaluate the relationship between plant performance in terms of nutrient removal efficiency and the variability of effluent quality (e.g., TP, OP, TN, ON, NH_3-N, NO_X-N).
- Evaluate the capability of nitrification and nutrient removal plants to meet very low maximum day permits for ammonia.
- Briefly summarize the factors that affect nutrient removal and nitrification process reliability and the technological conclusions that can be drawn, based on the results of the survey.
- Identify the elements of plant design and operation that plant managers found particularly important in meeting their effluent requirements.

1.4 Organization

To accomplish the goals of the study with limited WERF funding for data collection, analysis and management, it was necessary to leverage the volunteer efforts of many individuals. The managers of the 22 participating plants were asked to provide data that could be analyzed statistically and to prepare technical papers on the plants. They also provided information on plant process flow diagrams, design criteria, and operational procedures and targets. Each year of the study culminated in a workshop held at WEFTEC. The first year was held in Chicago at WEFTEC 2008 and the second year in Orlando at WEFTEC 2009. Presentations were made by each of the managers as well as papers submitted. Both the papers and the presentations are now accessible to WERF subscribers on the WERF nutrient challenge knowledge area web page (http://www.werf.org/nutrients). The text for the plant descriptions included in this report were taken from these papers with only slight alteration. The significant efforts of these plant managers and their plant staff were essential to the success of this study. WEF volunteers worked with each of the speakers to assist where needed in providing peer review, answering questions on data needs and on what materials to include. The volunteers were selected on the basis that they were not involved in the design of the treatment facilities investigated, so that all strengths and weaknesses of the plants could be clearly portrayed without bias or "diplomatic" issues.

The Municipal Wastewater Treatment Design Committee of the Water Environment Federation (WEF) helped organize the volunteers who assisted the plant managers who participated in this investigation. WEF's participation in this investigation greatly expanded its scope, depth, and value. The contributions of the volunteers and plant managers (and their organizations) are gratefully acknowledged and are listed here: Walt Bailey, DC Water; Dale Belschner, WSSC; Ken Brischke, MWH: Charles Bott, VMI and HRSD: Kevin Clark, Pinery; Chris deBarbadillo, Black and Veatch; Don Dodson, JJ&G; Doug Drury, Clark County; Joni Emrick, Kalispell; Greg Farmer, Englewood; Kim Fries, CH2M; Mike Gosselin, Kelowna; Randall Gray, Reno Sparks; Jose Jimenez, Brown and Caldwell; Bruce Johnson, CH2M; Carl Koch, Greeley and Hansen; Ron Latimer, Hazen and Sawyer; Helen Littleton, JM&T; Tim Madhanagopal, Orange County; Chris Maher, Upper Blue Sanitation District; Jon Meyer, Lee County; Sudhir Murthy, DC Water; JB Neethling, HDR; Gary Newman, Brown and Caldwell; Maureen O'Shaughnessy, ASA; Jay Parker, T-TSA; Denny Parker, Brown and Caldwell; Phil Pedros, FR Mahoney; Mark Perry, HR&G; Dwayne Phillips, Hillsborough County; Richard Porter, Gwinnett County; Robert Rowland, Scituate; Jerry Seay, Kalkaska; Kevin Selock, WSSC; Mesut Sezgin, Atlanta; Nick Shirodkar, WSSC; Carlo Spani, Clean Water Services; Chris Tabor, CDM; Tom Wilson, AECOM; Warren Wilson, WPC; and Bob Wimmer, Black and Veatch.

An audience of more than 100 attendees at each of the WEF/WERF workshops 101 at WEFTEC 2008 and W216 at WEFTEC 2009 made valuable comments on the approach and interpretation of the data.

A project steering committee consisting of WEF members, WERF staff and contractors, and an EPA staff member helped provide guidance throughout this investigation. This steering committee included Charles Bott (chair, second year; member, first year) HRSD; Denny Parker (chair, first year; member, second year), Brown and Caldwell; Amit Pramanik, WERF; JB Neethling, HDR; Sudhir Murthy, DC Water; and Phil Zahreddine, EPA (member, second year).

CHAPTER 2.0

PROJECT APPROACH

Exemplary wastewater treatment plants were identified from past surveys and project team knowledge. Plant managers were approached as to their willingness to have their plants represented in this investigation as well as to volunteer their staff time to make the work a success. Only a very few of the plants approached declined participation, usually because of staff time limitations. Only plants that had accumulated 36 months of operating data were included; this necessarily caused certain emerging technologies to be excluded.

This project team was reliant in this investigation on the data available from each plant; no special sampling was conducted. All of the plant operating data that was provided and analyzed in this study were flow-proportioned, composite samples. As in the past for other WERF projects, plant operating data and analytical information was requested and accepted without independent confirmation of the analytical work. This approach is taken because of the stringent liabilities under existing federal regulations for misreporting data. Moreover, the exemplary plants in this study are under elevated regulatory scrutiny, and also have stringent and verifiable QA/QC procedures, given the environments to which they discharge.

No attempt was made to get into detail about the factors impacting the various unit processes within a plant; rather the attempt was to try to identify the treatment capabilities of different overall flow sheets in meeting stringent treatment objectives. In this regard, the study looked at individual treatment processes as building blocks towards contributing to effluent reliability. The disadvantages of this approach are recognized by the steering committee; for instance the current flow and loading relative to the design capacity obviously reflects the degree of "stress" placed on the plant. And stress testing coupled with plant modeling is obviously a key element in determining the capacity of an individual plant. WERF, in fact, has developed programs that include a stable of valuable protocols for stress testing and modeling components of plants (Parker et al., 1999; Melcer et al., 2003; Wahlberg, 2004; Wahlberg, 2006). None of these rating and modeling approaches supported a full evaluation of the treatment plant's reliability to achieve very low nutrient limits. Therefore, a supplementary approach was deemed necessary. The approach for this study was to identify those exemplary plants that had features which produce exceptional effluent quality and to use a common method to portray their reliability on a statistical basis. In using this approach, we acknowledge that the contributions of the specific dimensioning or specific features of a process (e.g., the different types of effluent filters) would remain opaque to the analyses that could be done during this project.

Another disadvantage of the project's approach is that for the most part, plants were operated below their design flows and loadings, and therefore were not challenged by the stressors of their design conditions. There is no doubt that the difficulties for managing operations to attain low effluent conditions are greater as any plant approaches its design conditions. The best that can be said in this circumstance is that to emulate the performance of the studied exemplary plants, excellent operation and conservative design must be employed. The plants often have specific measures built in to improve reliability. For instance, the F. Wayne Hill plant has the ability to divert "off spec" water to storage for later reprocessing. Such measures of course have costs, energy, and labor staffing implications. Nonetheless, the plants studied are real plants subject to variability in wastewater characteristics, unavoidable imperfections that are present in every design or operation and under market conditions, which at times cause disruption of key resources, such as reliability in chemical supply. In addition, the plants in some cases were subject to impacts of toxic events or construction scheduling impacts, which are not unusual in municipal wastewater treatment. Nothing was excluded from the data analyzed.

2.1 Statistical Analysis

Three years of final effluent data were subjected to a selection of statistical methods. For plants analyzed for nitrogen performance, total nitrogen (TN), ammonia nitrogen (NH_3-N), nitrate plus nitrite nitrogen (NO_X-N), and organic nitrogen (ON) were considered. In the case of one plant, only total Kjeldahl nitrogen (TKN) data was available, and NH_3-N data could not be analyzed separately. Also, two plants were analyzed for total inorganic nitrogen (TIN) instead of TN. For phosphorus removal plants, the analysis considered both total phosphorus (TP) and ortho-phosphate-P (OP); however, four of the plants did not collect OP data.

Prior to analyzing a plant's effluent data all values that were reported as zero, non-detectable, or as the minimum detection limit (MDL) were changed to half of the MDL for each constituent. For example, Truckee Meadows Water Reclamation Facility has a MDL for nitrate of 0.1 mg/L as N. Any nitrate value that Truckee Meadows reported as zero, non-detectable, or the less than the MDL for nitrate (0.1 mg/L) was changed to 0.05 mg/L as N. This was performed for two reasons. The first being that the statistical analysis requires non-zero numbers because the values are log-transformed, and secondly because consistency had to be maintained for all of the plants. After performing this initial step, TN, NO_X-N, and ON were recalculated (or calculated if the plant had not done so already) for the plants being analyzed for nitrogen performance to reflect the changes that were made.

It should be noted that some of the plants analyzed had large portions of NH_3-N and NO_X-N data reported at or below their respective MDL. This results in data distribution that does not closely follow an assumed log-normal distribution. This is recognized as a limitation of calculating reliability using equation 1.2-4 and is discussed in further detail in Section 3.4.1.1.

2.1.1 Probability Calculations

Summary statistics were calculated for the full data set including the arithmetic average (mean), geometric mean, standard deviation, coefficient of variance (CoV), skew, minimum, and maximum. A time series plot was prepared from the data with the discharge limits and median values shown on the graphs. A range of percentile statistics were also calculated from the same data set including the 3.84^{th}, 50^{th} (median value), 90^{th}, 95^{th}, and 99^{th} values. These percentiles are referred to herein as the probability that a value is less than or equal to the stated concentration. The data were then ranked, and the Weibull probability was calculated according to:

$$P = \frac{\text{rank}}{n+1} \qquad (2.1\text{-}1)$$

where P is the probability and n is the number of data points in the set.

The concentration values were plotted versus the probability (less than or equal to) using SigmaPlot 11.0 (Systat Software, Inc.) with the y-axis converted to a log scale to reflect the log-normal transformation, and the x-axis plotted using the normal distribution probability scale. Although all other calculations were done using Microsoft Excel for the sake of simplicity, probability plots were generated using SigmaPlot because Excel does not have the capability to generate a probability scale without significant manual graph manipulations and programming.

The probability plots developed for this project include both the data plotted as points, as well as a line (colored red throughout this report) that represents the ideal log-normal distribution of the data. It is important to recognize that this line is not the "best-fit" of the data, but rather the expected "shape" of the curve if the data were ideally log-normally distributed. To obtain this line, the data set was log-normally transformed (by taking the natural log of each value in the data set), and the expected probabilities were determined by computing the log-normal Z using the log-transformed mean and standard deviation. The normal probability associated with this Z value was used to calculate the expected probability (using the =NORMSDIST(x) function in Excel). Excel does include a log-normal probability function that can be used directly without evaluating the normal Z value (=LOGNORMDIST(x, mean of ln(x), std. dev. of ln(x))), but this function does not preclude log-transforming the data because it requires as input the log-transformed mean and standard deviation. The data were plotted as a line (red) versus the expected log-normal probability for each of the probability plots.

The full data set was then subjected to a 30-day rolling average and all of the manipulations described above were performed including summary statistics, percentile calculations (probabilities), time series plot, and probability plot. Monthly average values were computed for the data set, and these monthly average values were subjected to the same analysis. Finally, a 12-month rolling average (annual average) of the monthly averages was calculated and again subjected to the same statistical methods. As a result, each data set yielded four sets of summary statistics and four probability plots (raw daily data, 30-day rolling average, monthly average, annual average).

The 30-day rolling averages, also referred to as a moving averages, were calculated by averaging 30 consecutive daily data points, with 14 data points occurring before the given date and 15 data points after. Since only three years of data (1096 data points when including one leap year) was provided for each plant, the 30-day rolling averages at the beginning and end of the data sets were calculated differently. For the beginning of a data set, the first 15 averages were calculated using the same first 30 data points. For the end of a data set, the last 15 averages were calculated using the same methodology as was for the bulk of the data points except for as the rolling average approached the end of the data set, the number of data points used to calculate the average decreased by one point. For example, data point 1081 (out of 1096 data points), would be determined using 30 daily data points, data point 1082 would be determined using 29 daily data points, and so on until the very last average (data point 1096) is determined using only 15 daily data points. The purpose of this methodology, as opposed to omitting the first 15 and last 15 rolling averages, was to ensure that a full three years of data (1096 data points with leap year) was obtained for analysis.

It should be recognized that many of the plants did not collect daily samples. When 30-day rolling averages are calculated, the averages span gaps in the data resulting in a full three years of 30-day rolling average data points. As a result, the rolling average represents a true 30-day rolling average, not a 30 data point rolling average. For example, a plant that only collects samples three times a week would only have 468 daily data points. Performing a 30-day rolling average of this data would result in 1096 data points.

The monthly averages were calculated by computing an average for each month which resulted in 36 data points. These 36 data points were subjected to a 12-month rolling average using the same methodology that was used when computing the 30-day rolling averages. Throughout this report, 12-month rolling average values are referred to as annual average values.

2.1.2 Reliability Calculations

Equation 1.2-4 was used to compute the reliability of each of the nutrient removal processes to meet treatment objectives specified both by the discharge permit limit and a selection of reasonable values. For example, the reliability was calculated for TN at the exact permit limit value, but if the reliability was quite high, several concentration values below the permit limit were also selected. For NH_3-N and NO_X-N, since no permit limit was defined (or in the case of NH_3-N, the permit limit was not critical relative to the TN limit) it was necessary to choose relevant concentrations for which to evaluate the reliability of the plant, to some degree based on the actual performance process. It is important to recognize the simplicity of this method in terms of computing the reliability of a plant to meet a permit limit given an effluent data set. With the application of Excel or other statistical software package, this is something that could be performed by treatment plants on a regular basis to better track process performance and variability (really reliability). This calculation is just as straightforward as percentile statistic calculations and does not require probability plot construction, as long as the log-normal distribution is assumed. However, reliability was calculated for all of the plants in this study using equation 1.2-4 regardless of whether or not a plant's data set conformed to log-normal distribution and this limitation should be recognized.

The validity of the approach used here to compute reliability directly from a data set using equation 1.2-4 depends on the degree to which the data fits the log-normal distribution. Briefly, the concept of process reliability is best understood by first considering the information available on the probability plots generated as part of this study. It is important to recognize that process **reliability** and **probability** are really one and the same (Figure 2-1 and Table 2-1). The probabilities presented in this report were all derived directly from percentile statistics, but they could also be determined from probability plots by choosing a desired probability on the x-axis of Figure 2-1 (following the blue line), moving vertically up to the **data points** and left to the y-axis to determine the concentration value. Theoretically, these methods should result in exactly the same value, and this concept with respect to probability plot usage is common knowledge to most in the field.

The log-normal line is also plotted in Figure 2-1 demonstrating a relatively good fit of the data to the log-normal distribution but with some deviation at the high concentration range. Since the data are well fitted to the log-normal distribution, one could also determine the probability by choosing the value on the red line in Figure 2-1, and in fact this value can be calculated explicitly (not done here). In addition, if one assumes that the log-normal distribution is valid, one can also determine the probability (referred to as **reliability** for this report) associated with a given concentration by following the green line in Figure 2-1. It turns out that this value, however, can be easily calculated using equation 1.2-4, with no need to pick values off the probability plot. It is important to emphasize that the value of this approach, as developed by Niku and Schroeder (1979), and applied by Oliveira and Sperling (2008), is quite useful because the reliability can be easily calculated from the data set at a chosen concentration, likely at the permit requirement. The 0.05 mg/L TP concentration represents the annual average permit limit for the Iowa Hill WRF in Breckenridge, CO at the design flow of 1.5 MGD, and the reliability at this concentration is 95.7%.

Therefore, the working definition here is that **reliability** is computed using equation 1.2-4 and assumes the log-normal distribution is valid. The **probability** values reported here are taken directly from the data as simple percentile statistics, similar to picking values off a probability plot. Clearly it is possible to determine the reliability at a chosen concentration without relying on the log-normal distribution assumption simply by selecting values from a probability plot, but that was not done here and explains the slight discrepancies in some of the reliability and probability values in the figures presented herein. Fundamentally though, reliability and probability are exactly the same thing, but with two different starting points. From a utilitarian perspective, the wastewater treatment industry overall is most interested in selecting a set of reasonable and appropriate probability values to compare one plant or process to another, but a utility manager is probably more interested in the reliability of the that particular treatment plant or process at the permit limit.

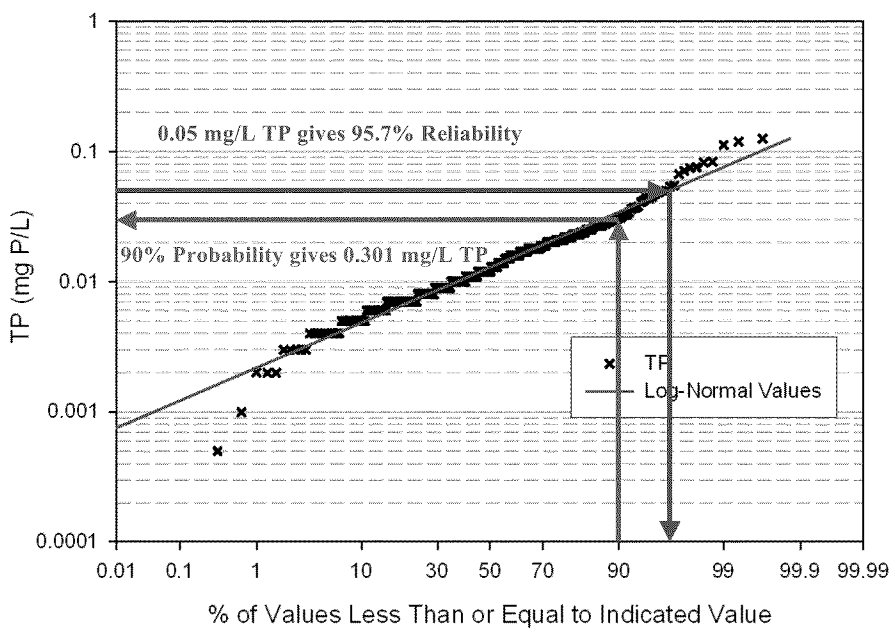

Figure 2-1. Probability Plot for Daily TP Data for the Iowa Hill WRF, Breckenridge, CO.

Table 2-1. TP Probability Values from Percentile Statistics Derived from Data and Calculated TP Reliabilities Computed Using Equation 1.2-4 and Selected TP Treatment Objectives for the Iowa Hill WRF.
Note that the Reliability Calculations Assume that the Data are Log-normally Distributed.

Probability (%)	TP (mg/L)	Reliability (%)	TP (mg/L)
50	0.0120	39.1	0.010
90	0.0301	71.9	0.020
95	0.0451	86.0	0.030
99	0.0843	95.7	0.050

2.2 Technology Performance Statistics

The performance of a treatment technology or process is defined in this report using percentile statistics that are referred to as Technology Performance Statistics or TPSs. Three TPS levels are evaluated to represent the ideal, the median, and the reliably achievable performance. The approach can be used to determine the ideal performance, the reliable performance, or other descriptor that allows for a rational interpretation of the results. This presentation must also include the source of the data and the conditions under which data is collected. For example, performance could change for the same application when the plant is experiencing normal loadings versus a year when unseasonably high peak flows and cold temperatures are experienced.

The term Technology Performance Statistic or TPS is used to describe the performance measured from a specific technology. Because the performance of a process can be manipulated by the operator and is affected by many factors, the TPS must be defined in terms of the specific conditions under which the data is collected. Table 2-2 shows the key conditions that affect performance of a technology and the data collected. The information in Table 2-2 should be reported along with TPS values whenever possible.

Table 2-2. Specific Conditions Associated with Technology Performance Statistics.

Condition	Report	Significance
Treatment goal	Numerical value and period	The treatment goal is typically the regulatory permit limit. In some cases, the goal is lower than the permit. This represents the main target for the operator. Operators can choose to reduce chemicals, energy consumption, etc. to increase efficiency.
Data source	Data source, period, frequency	Regulatory controlled data (permit reports) are the most commonly used data source. Data is assumed to be from a certified laboratory. The dataset duration (number years) and frequency of data collected (samples per period) should be noted. Averaging of data (monthly reports) can be used under certain circumstances; daily data is commonly used.
Season or period	Season	The data period of data collection impacts the conclusion regarding performance. If the dataset is less than a year, no firm conclusions regarding annual operation can be drawn (unless the plant experiences no seasonal changes).
Exclusions	Conditions or data excluded	In some cases a known problem may skew the data (construction, for example). This should not be used to eliminate "poor" or "good" data.
Treatment capacity	Load and capacity	Plants typically operate below their design capacity.
Scale	Pilot, bench, full, etc.	The scale of the process impacts the ability to control the performance. Plants (pilot or other) that have the ability to fully control the influent composition or flow will typically perform better.
Solids processing	Type and recycle stream management	Recycle streams from solids processing could impact performance of nutrient removal and nitrification plants attempting to achieve low limits.
Special conditions	Special conditions	Special conditions that applies to the application. Industrial contributions, extreme cold or warm conditions, seasonal visitors, or slug loads, etc.

The conditions in Table 2-2 address the external factors that may affect performance. For example, a permit requirement of 1.0 mg/L TP would dictate the level of care and effort needed from the operator to meet the permit in an economical way. Internal operational conditions (such as chemical addition, amount of chemicals added, sludge age, loading rates, etc.) that are within the control of the operator would affect the performance. That does not mean the data is "bad" or not representative, but that it reflects the constraints or targets set for the operation. Successful operation for the plant is defined by its ability to meet the permit – not necessarily to exceed the permit.

In some applications, the treatment goal is "the best possible performance." These cases are typically associated with internal agency goals, technology demonstrations, or some other factors. Data collected under these conditions would represent the best achievable performance.

Data from pilot or bench scale processes are typically sheltered from normal fluctuations experienced by full scale facilities. Many pilot and demonstration units are operated under steady state conditions and well-controlled environments, removed from the impacts of slug loads or solids processing. The performance from these applications should be more reliable and achieve better results than the same technology when operated under "real world" conditions.

Three Technology Performance Statistics are proposed: the ideal, the median, and the reliable.

2.2.1 Ideal Technology Performance Statistic

The ideal Technology Performance Statistic provides an unbiased value of the ideal performance of the technology – when it is minimally influenced by all the factors that cause statistical variability in real plants. These conditions are ones that likely replicate those ideal conditions that might be obtained under controlled laboratory conditions with defined, treatable influents. For full scale performance, the ideal TPS represent the lowest concentrations (idealistic performance) observed. The ideal TPS is defined as the statistically-computed performance under the conditions of operation that can be sustained for a short period of time. The project steering committee proposed that the lowest TPS achievable concentration is **the performance that remains sustainable for a two week period in one year.** Note that the 14-day TPS, or TPS-14d, is exceeded 50 out of 52 weeks per year and is definitely not an appropriate permit limit. Beyond influent variability other realistic factors determine plant performance not captured by this statistic including variable climatic conditions during a year, process control corrections which may lag periods of lower performance, ability to automate the process, specific attributes of the service area such as seasonal loadings, discontinuous impacts of commercial industrial contributions, mechanical or sensor failures, impacts of solids processing returns, and human error. The 14-day TPS is proposed instead for other reasons. BNR processes operate over a large range of sludge age conditions, but typically at a sludge age between 8 and 20 days. A two week period would therefore capture one sludge age of operation for a number of the plants.

The ideal TPS can be determined from operating data by determining the 3.84th percentile (14/365 = 3.84%), assuming the data are randomly distributed (wastewater treatment plant data are typically log-normal distributed). A more detailed explanation of the approach and methodology for determining this technology performance statistic is provided in Neethling et al. (2009).

2.2.2 Median Technology Performance Statistic

The median Technology Performance Statistic (TPS-50%) represents a measure of the concentration that was achieved on a statistical annual average basis. The project team used the median (the 50th percentile data number) in this study rather than the arithmetic average, because it is impacted less by extreme values resulting from upset events. In this study the TPS-50% is used to develop ratios from the reliable TPS values in order to indicate how much performance deviates from the average performance to the reliable levels as a function of effluent requirements and averaging periods. And technologies with consistently low variability can inform designers and managers about the need for measures to use in design.

2.2.3 Reliable Technology Performance Statistic

The reliable TPS does not represent a single percentile value for an averaging period (e.g., 95th or 99th percentile). Rather, it is a selected value depending on the technology, the averaging period used in the permit and the frequency of violations during the permit period selected by the plant owner based on the utility's risk tolerance. Using the TPS notation, the 90th, 95th, and 99th percentiles would be noted as the TPS-90%, TPS-95%, and TPS-99%, respectively.

Monthly based permits are commonly used in practice, since compliance reports are filed monthly and permits set maximum month limits. Plant performance and assessment of its ability to comply with monthly limits should not be based on average or even 91.7th percentile (11/12th percentile). The 91.7th percentile is the treatment level exceeded once a year – in other words, the plant will fail one month per year.

2.2.4 Technology Variability from TPS-14d Performance

Treatment plants operate under variable conditions. Beyond daily diurnal variation, plants experience seasonal patterns. These fairly predictable patterns include flow and load variations. Municipal plants serving bedroom communities often follow a typical diurnal flow pattern with peaks occurring in the morning and early evening. Load variations are more difficult to predict and may or may not coincide with flow variations. In addition, some constituents may peak at different times; for example, ammonia peaks often occur in the very early morning and late evening, while BOD peaks tend to be more moderate and more closely follow flow variations. This means that the composition of the wastewater (BOD/N and other ratios) change during the course of the typical day.

Shorter duration fluctuations are more difficult to manage – these include external factors (a rain storm for example) or internal factors (operating dewatering equipment and returning the liquid to the plant intermittently). Construction activities, equipment failure, toxicity, etc. cause effluent excursions and impacts the performance. These impacts are magnified for shorter duration averaging periods (monthly, weekly, daily).

Deviations from the lowest achievable performance can be assessed using the relationship between the TPS values, by determining the ratio of the 3.84th, 50th, and 95th percentiles as a measure of variability. The ratio between these values represents the variability of performance, and it provides a measure of the differences in performance between the lowest, median, and maximum month limits. The ratio of the 50th to 3.84th percentile represents the difference between the average annual performance achievable compared to the ideal TPS-14d, while the 95th to 50th percentile represents the ability of a technology to meet monthly limits compared to annual values. (Note that 95th percentile values for monthly permits would not normally would be used for permit setting, as noted later.)

These variability measures will allow designers to make judgments about the various technologies to meet permit limits consistently. Low variability means that designers may include less conservatism in their design of new facilities. Permit limit averaging time (average, monthly, weekly) will determine the acceptable variability.

2.3 Technology Evaluation

As noted previously, data were analyzed two ways, both on a probability basis and on a reliability basis. Only the former method is used in the technology evaluation. While log-normal distributions were fit to the data, the data themselves were used to calculate effluent values according to common percentage probabilities, since the ideal log-normal curves tended to depart from the data in the region of most interest (low and high concentrations). While the full distributions were reported for each plant in the plant presentations, the concentrations that were the focus of the technology evaluation corresponding to daily, rolling 30-day average, monthly, and annual averages were the 50th, 90th, 95th and 99th percentile values. To give these values meaning in terms of violations per the five-year National Pollutant Discharge Elimination System (NPDES) permit period, Table 2-3 reports the number of exceedances per permit period for each of these values.

Table 2-3. Number of Exceedances Per Five-Year NPDES Permit Period for Daily, Monthly, and Annual Average Permits for Given Percentile Values.

Percentile Less than Stated Concentration	Daily (with Daily Sampling)	Monthly	Annual Average
Total reporting events in 5 years	1826	60	5
50	912	30	2.5
90	183	6	0.5 (or 1 per 2 permit periods) [a]
95	91	3	0.25 (or 1 per 4 permit periods) [a]
99	18	0.6 (or 1 per 2 permit periods) [a]	0.05 (or 1 per 20 permit periods) [a]

Note:
a. These percentile values can only be calculated assuming the longer periods are adequately represented by 36 months of data.

While the steering committee believes that the approach taken is more comprehensive than previously undertaken, it is not asserted that there were no limitations to the investigation's approach. In picking only three years of data to evaluate, projecting concentrations for longer periods (e.g., 10-20 years) is a significant extrapolation and may not represent all of the events that could impact the reliability of plants striving to attain low levels for nutrient removal.

The committee therefore took the pragmatic approach of using the 95th percentile values to rate the technologies on a monthly basis. While the 95th percentile values were used to assess the technologies, it must be recognized that setting maximum monthly permits for a nutrient on this basis results in an exceedance of three times per permit period (Table 2-3). As noted later, this may not be an acceptable result for either the permitted utility or industry or the permit writer. Using the annual average data for the permitted nutrient in question on a 95th percentile basis for an NPDES permit results in a permit that would be exceeded once in 20 years or four permit periods. This investigation gives some examples of using higher percentile values as they would have even less frequent violations for the same data set.

By obtaining a large data set on each plant and analyzing its reliability on a statistical basis, it was postulated that by comparing and contrasting the plants, some valid conclusions could be drawn about the following:

- The importance of technology in contributing to plant performance.
- By comparing similar plants with similar features, the role of climatic conditions (particularly wastewater temperature) might be deduced.
- The role of specific effluent requirements on the design and operational procedures and its impact.
- Evaluation of alternative statistical bases for permit writing, particularly rationale for picking representative maximum month alternatives as well as maximum day, annual averages and others.

CHAPTER 3.0

PLANTS SURVEYED

3.1 Data Provided

Managers of 22 plants provided final effluent data that could be analyzed statistically and prepared technical papers on the plants. The managers also provided information on plant process flow sheets, influent characteristics, chemical feed rates, process operating data, process design criteria, operational procedures and targets, discharge limits, and general observations of data nuances. Three years (36 months) of plant operating data and analytical information was requested and accepted without independent confirmation of the analytical work, but in this case, all of the statistical evaluation work was focused on the final effluent data. Nothing was excluded from the data sets that were analyzed herein. The three linear or consecutive years of data encapsulates 12 full seasons without emphasizing any particular season or year. The purpose was to analysis a manageable amount of recent data that includes yearly fluctuations. That being said, in order to maintain consistency, every plant was analyzed from January 1, 2005 to December 31, 2007. However, there were a few exceptions due to permit changes or insufficient data during the specified time period. In all cases, every plant was analyzed for a period of exactly three years (36 months). One example where a plant was not analyzed during the stated period was the Truckee Meadows plant. Initial analysis emphasized a period of significant nitrification inhibition caused by an unavoidable toxic load experienced at the plant. Obviously, this single event was not reoccurring and indicative of typical conditions at the plant. Therefore, an additional analysis was performed that did not include the time period in which the inhibition occurred. Truckee Meadows was still analyzed using exactly 36 months of data.

3.2 Process Building Blocks

The process building blocks that make up the liquid process flow sheets investigated are identified in Figure 3-1. This figure is the key to understanding the individual plant flow sheets presented later. Note that the building blocks are representative, not definitive. For instance, the symbol for a primary clarifier shows a rectangular tank. This symbol is used throughout even though a plant may have circular primary clarifiers.

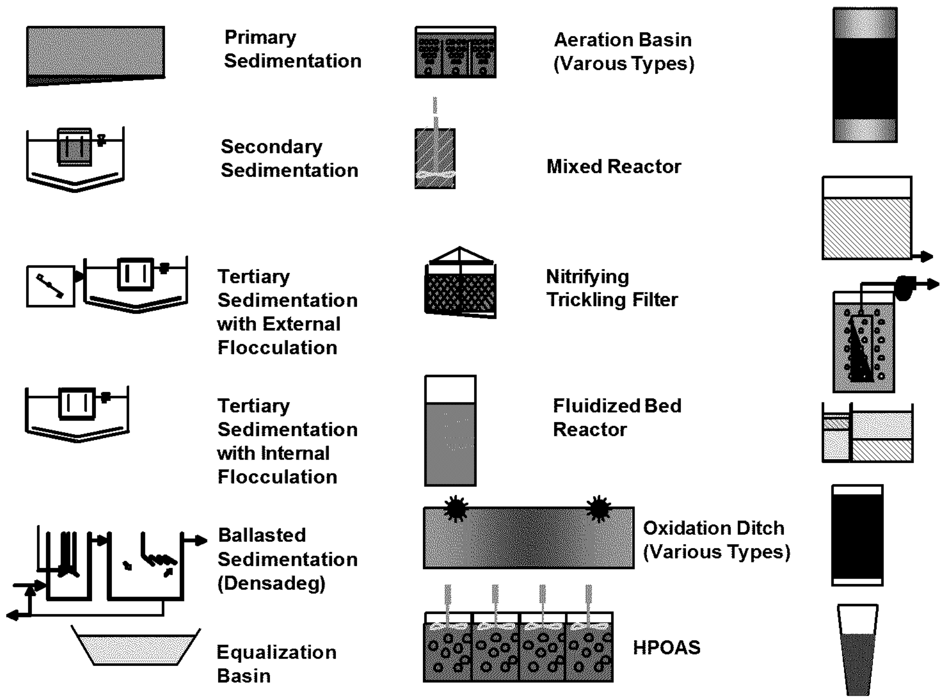

Figure 3-1. Unit Process Building Blocks.

3.3 Summary of Plants

As mentioned before, 22 plants were selected based on their exceptional performance. Each plant was analyzed according to its capability to remove either nitrogen or phosphorus or reliably nitrify. The majority of the plants simultaneously removed both nitrogen and phosphorus to some degree. The selection to analyze a plant for a particular nutrient was based on which discharge limit actually controlled the overall operation of the plant. The project team did not want to limit the study to certain technologies or processes. Therefore, an attempt was made to analyze a wide variety of processes that were located in both warm and cold climates. A summary of all of the plants that were included in this study is provided below. Table 3-1 lists the plants that were analyzed for the overall removal of nitrogen. Table 3-2 lists the plants that were analyzed for the overall removal of phosphorus. Table 3-3 lists the plants that were analyzed for nitrification reliability only. The plants included for nitrification reliability were not necessarily required to meet stringent TN effluent limits. The purpose of including these plants in this study was to evaluate the statistical reliability of nitrification while trying to meet exceptionally low ammonia limits. The plants were classified according to minimum wastewater temperatures according to the following scheme: greater than 20°C, warm; 15 to 20°C, moderate; 12 to 15°C, cold; and less than 12°C, very cold.

Table 3-1. Nitrogen Removal Plants.

Process Type/Facility	Cold or Warm
Separate Stage N Removal	
River Oaks, FL	Warm
Western Branch, MD	Cold
Truckee Meadows, NV	Cold
Scituate, MA	Very Cold
Tahoe-Truckee, CA	Very Cold
Combined N Removal	
Eastern, FL	Warm
Parkway, MD	Cold
Piscataway, MD	Cold
Multiple Stage N Removal	
Fiesta Village, FL	Warm

Table 3-2. Phosphorus Removal Plants.

Process Type/Facility	Cold or Warm
Single Stage Chemical Addition	
Iowa Hill WRF, CO	Very Cold
F. Wayne Hill, GA	Moderate
Cauley Creek, GA	Moderate
Pinery, CO	Cold
Multiple Stage Chemical Addition	
Clark County, NV	Moderate
Rock Creek, OR	Very Cold
Blue Plains, DC	Cold
ASA, VA	Cold
Biological Phosphorus Removal, Minimal or No Chemical Addition	
Kelowna, BC	Cold
Kalispell, MT	Very Cold

Table 3-3. Nitrification Reliability Plants.

Process Type/Facility	Cold or Warm
Activated Sludge	
Kalkaska, MI	Very Cold
Utoy Creek, GA	Cold
Biofilm Reactor	
Littleton/Englewood, CO	Cold

3.4 Nitrogen Removal Plants

3.4.1 Truckee Meadows Water Reclamation Facility, NV

The Truckee Meadows Water Reclamation Facility (TMWRF) began treating water in 1967. The original plant was a secondary treatment facility which utilized basic conventional activated sludge processes. During the late 1970s nutrient requirements became a concern in the region and a Phostrip process was constructed for phosphorus removal. Additions were made on existing tanks as well as new tanks were constructed. During the 1980s nitrogen requirements were placed on the facility discharge permit. Once again new processes were added on to the treatment train. The additions included nitrification towers, Envirex upflow fluidized sand beds for denitrification and multimedia gravity sand filters for effluent polishing. With all the current knowledge related to nutrient removal there could be much debate on how to best configure the TMWRF facility. It could be argued that the way processes were added on over time and that it introduced inefficiencies and increased treatment cost. The major inefficiencies of concern are related to electrical power usage as well the need to purchase large amounts of methanol for denitrification. In spite of these increased costs the chosen treatment scheme does reliably produce a quality effluent that has very low total nitrogen concentrations.

The TMWRF is located in north western Nevada and serves the Cities of Reno and Sparks. The treatment facility was originally placed in service in 1967. This facility currently serves a combined population of approximately 310,000 people. A major construction project was completed at TMWRF in March 2007. The project provided 4.6 MGD of additional capacity and process improvements. The facility has hydraulic treatment capacity of 46.5 MGD and is currently processing 30 MGD. The major treatment steps include bar screening for rag removal, gravity grit removal tanks, primary sedimentation tanks, biological phosphorus removal in the activated sludge process, secondary clarification, nitrification trickling filters, upflow fluidized sand reactors for denitrification, gravity sand\anthracite coal filtration, bleach chlorination disinfection, and sodium sulfite de-chlorination. The Phostrip process feature is no longer used. Waste sludge from primary clarification is thickened in gravity thickeners prior to being pumped to sludge digestion. Waste activated sludge is thickened in dissolved air flotation units and pumped to sludge digestion. The sludge digestion system incorporates one acid phase digester tank followed by five mesophilic digesters. Digested biosolids are dewatered with centrifuges prior to being hauled to a local landfill for disposal. See Figure 3-2 for the facility process schematic and Table 3-4 for the design raw influent wastewater parameters and average raw influent concentrations.

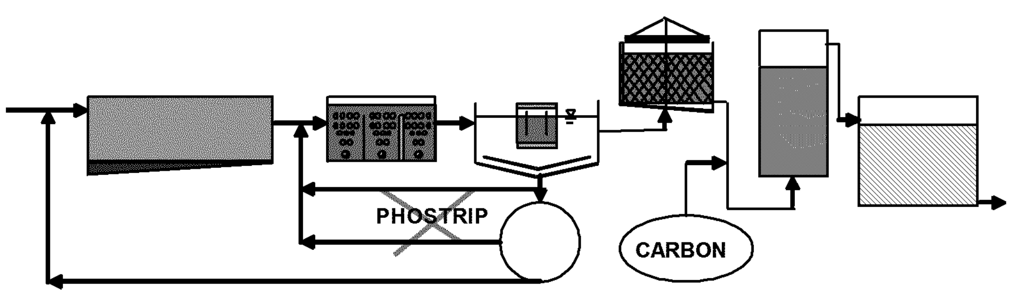

Figure 3-2. Truckee Meadows Process Flow Diagram.

Table 3-4. Design and Average Raw Influent Concentrations and Percent of Design Loads for the TMWRF from April 2006 Until March 2009.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	46.5	25.4 [c]	55
BOD_5 (mg/L)	172	225	71
$cBOD_5$ (mg/L)	N/A	193	N/A
TSS (mg/L)	149	171	63
Ammonia (mg/L)	26	28	59
TKN (mg/L)	29.8 [b]	N/A	N/A
TP (mg/L)	5.4	5.8	59
Temperature (°C)	N/A	18.6 [c]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Raw influent design value as TN. Percent of design assumes average raw influent TKN is approximately equal to TN.
c. Average final effluent value.
d. N/A: Data not available or applicable.

The plant is required to meet a discharge limit of 500 lbs./day TN and 134 lbs./day TP. See Table 3-5 for details on the discharge requirements. At the maximum design flow (46.5 MGD) this results in a discharge limit of 1.3 mg/L TN and 0.31 mg/L TP. The current influent flow rate of 30 MGD along with effluent reuse of up to 12 MGD during peak irrigation periods provides limited relief. As increases in population and influent flows occur over time discharge limits will progressively be more difficult to meet.

Table 3-5. Current NPDES Permit Limits as of October 2009 at TMWRF.

Parameter	30-Day Average	Daily Max
BOD (mg/L)	20	30
TSS (mg/L)	20	30
TP (mg/L)	0.4	N/A
TP (lbs/day)	134[a]	N/A
Nitrate (mg/L)	N/A	2.0
TN (lbs/day) (May-Oct)	500[a]	N/A
TN (lbs/day) (Yearly Average)	500[a]	N/A
TN (mg/L) (30 MGD)	N/A	2.0[b]
TN (mg/L) (40 MGD)	N/A	1.5[b]

Note:
a. TMDL required.
b. Flow weighted average using TMDL at a specified flow rate; not a permit limit.
c. N/A: Data not available or applicable.

3.4.1.1 Example Nitrogen Removal Data Set – TMWRF

Historical operating data from April 2006 through March 2009 was analyzed. During this period, the facility experienced a series of toxic events, from January 2005 through April 2006, affecting the overall performance of the plant. After April 2006, no major process upsets were identified in the data. The toxicity events affected the plant performance during 15 months (or 29% of the entire period). Based on the entire data set from 2005 through 2009, the facility has effluent daily and 30-day median TN values of 1.69 mg/L and 1.77 mg/L with maximum daily and maximum 30-day values of 6.85 mg/L and 3.11 mg/L, respectively. However, if the periods where high effluent TN levels were experienced from toxic events (January 2005 through April 2006) are eliminated from the data set, the overall daily and 30-day median values would be approximately 1.57 mg/L (daily) and 1.64 mg/L (30-day) with and daily and 30-day maximum TN values of 3.35 mg/L (maximum daily) and 2.07 mg/L (maximum 30-d), respectively.

Figure 3-3 through Figure 3-6 and Table 3-6 through Table 3-9 provide examples of the statistical summary compiled for the TMWRF in Reno, Nevada which has a flow weighted annual average TN limit of 2.0 mg/L at 30 MGD and 1.5 mg/L at 40 MGD. Several observations are provided for these data:

- Figure 3-3: Comparing the 30-day rolling average TN to the 2.0 mg/L annual average limit, it would appear that the treatment objective was not met during several periods during the three years that the data spans. (Note this was not a regulatory violation since the permit is based on annual averages.) The cause of the elevated effluent TN appears to have been caused by nitrification problems and high effluent NH_3-N.
- Figure 3-4: Probability plots suggest relatively good conformance with the log-normal distribution for TN and ON, with some deviation at high concentration. If the distribution behaves as indicated for NO_X-N and NH_3-N, it is clear that calculating reliability based on an assumed log-normal distribution (using equation 1.2-4) will not provide accurate information. As such, it would be advised in this case to calculate probabilities using the data directly (percentile statistics) or to obtain reliability values from a probability plot. As expected with averaging of the data set and attenuation of the upset events during longer averaging periods, better log-normal conformance is observed for all nitrogen species in Figure 3-4B, Figure 3-4C, and Figure 3-4D.
- Figure 3-4A: It is clear that the majority of the effluent TN is comprised of ON, but the ON concentration is relatively stable. Most of the process variability comes as a result of the nitrification process, with periods of high effluent NH_3-N impacting the TN. The denitrification process appears to be more stable than the nitrification process, and it appears that periods of high effluent NO_X-N do not impact much the effluent TN.
- Table 3-9 and Figure 3-5: If only one year of data was examined, the maximum value (Table 3-6) for the 30-day rolling average and monthly average data should be roughly equal to the 92nd percentile, which approximates the maximum month condition. Considering the database had 36 months and the range shown in Figure 3-5 for the daily 90-95% probabilities, the 30-day rolling average and monthly average maximum values for all four constituents are slightly higher than the 95% probability.
- For Figure 3-5, it is apparent that the concentrations associated with the 90, 95, and 99% probabilities decrease with data averaging, moving from daily data to the annual average. This is due to the fact that the averaging tends to attenuate the high concentration peaks making the plant appear to be more reliable. However, it is not as clear why in Figure 3-6 the predicted reliability tends to decrease at low concentrations and increase at higher

concentrations with data averaging. To explain this, it is easier to start at the high concentration range (high reliability). The fact that the reliability tends to increase is exactly the same as the decrease in concentration in Figure 3-5; the data become less variable with averaging and reliability increases at a given concentration (Figure 3-6), or the concentration at a given probability decreases (Figure 3-5). For the lower concentrations in Figure 3-6, the reliability tends to decrease with averaging because compared to the target concentration, less variability suggests more certainty that the treatment objective cannot be met. Similarly, if one were to determine the probability in Figure 3-5 at values less than 50%, the concentration would increase with averaging.

- The reliability at 2.0 mg/L TN based on daily data is somewhat above 70% suggesting that annual average compliance should be expected.

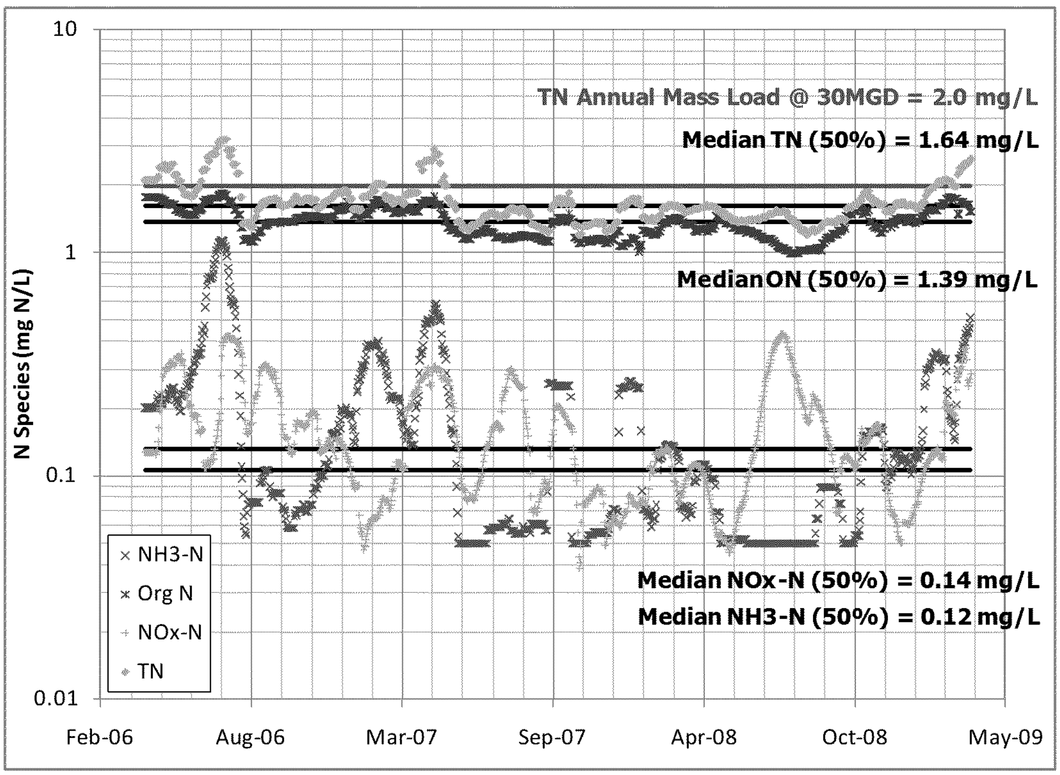

Figure 3-3. 30-Day Rolling Average Time Series Plot for TMWRF.

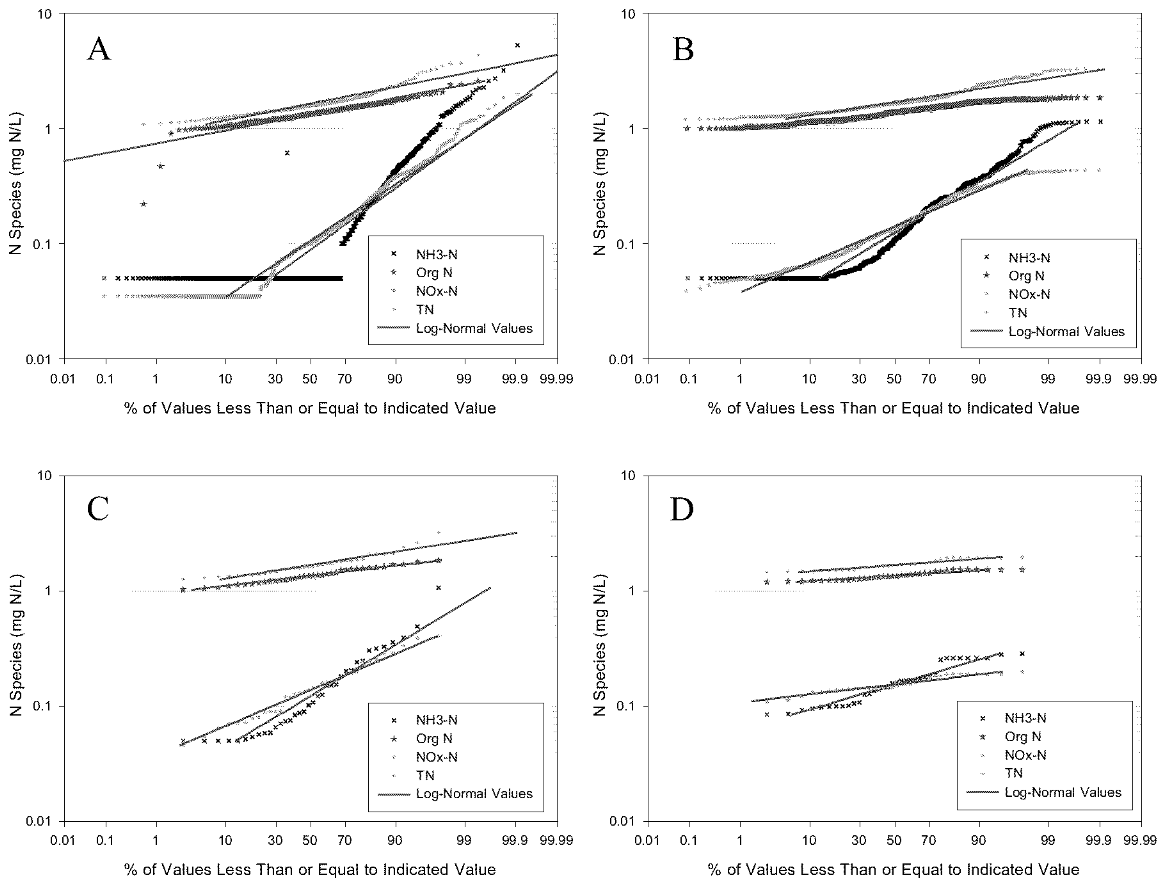

Figure 3-4. Probability Plots for TMWRF –
(A) Daily Data; (B) 30-day Rolling Average; (C) Monthly Averages; (D) Annual Average.

Table 3-6. Summary Statistics of Final Effluent NH_3-N for TMWRF.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	1096	1096	36	36
Mean	0.18	0.17	0.18	0.17
Geometric Mean	0.089	0.12	0.12	0.15
Std. Dev.	0.35	0.18	0.19	0.065
CoV	1.97	1.03	1.09	0.39
Skew	6.11	2.74	3.20	0.56
Minimum	0.050	0.050	0.050	0.084
Maximum	5.26	1.14	1.07	0.29

Table 3-7. Summary Statistics of Final Effluent ON for TMWRF.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	170	1096	36	36
Mean	1.36	1.37	1.38	1.37
Geometric Mean	1.33	1.36	1.36	1.36
Std. Dev.	0.31	0.21	0.22	0.12
CoV	0.23	0.15	0.16	0.084
Skew	0.64	0.27	0.34	0.22
Minimum	0.22	1.00	1.03	1.20
Maximum	2.57	1.85	1.85	1.53

Table 3-8. Summary Statistics of Final Effluent NO_X-N for TMWRF.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	1096	1096	36	36
Mean	0.16	0.16	0.16	0.16
Geometric Mean	0.11	0.14	0.14	0.15
Std. Dev.	0.19	0.093	0.092	0.024
CoV	1.20	0.58	0.57	0.15
Skew	3.88	1.00	1.08	0.14
Minimum	0.035	0.038	0.046	0.11
Maximum	1.97	0.43	0.40	0.20

Table 3-9. Summary Statistics of Final Effluent TN for TMWRF.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	170	1096	36	36
Mean	1.70	1.71	1.72	1.69
Geometric Mean	1.64	1.68	1.68	1.68
Std. Dev.	0.53	0.39	0.40	0.17
CoV	0.31	0.23	0.24	0.10
Skew	2.18	1.51	1.83	0.35
Minimum	1.09	1.20	1.27	1.46
Maximum	4.35	3.23	3.21	1.98

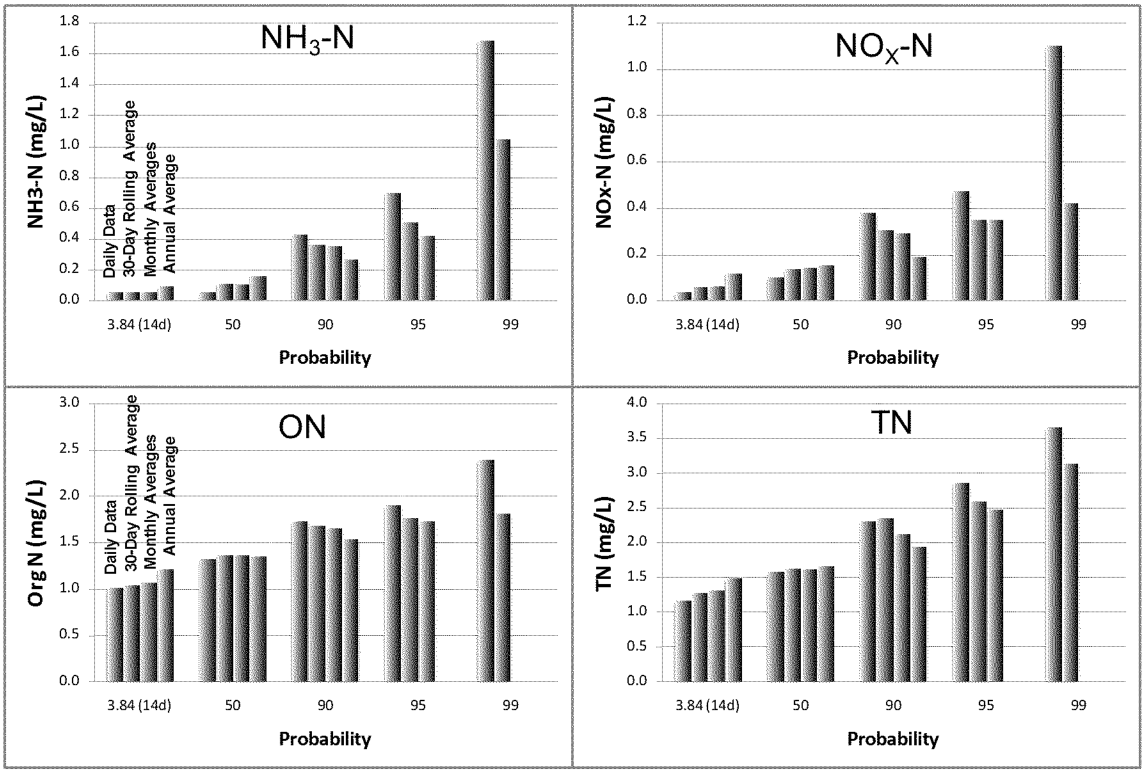

Figure 3-5. Probability Summary for TMWRF.

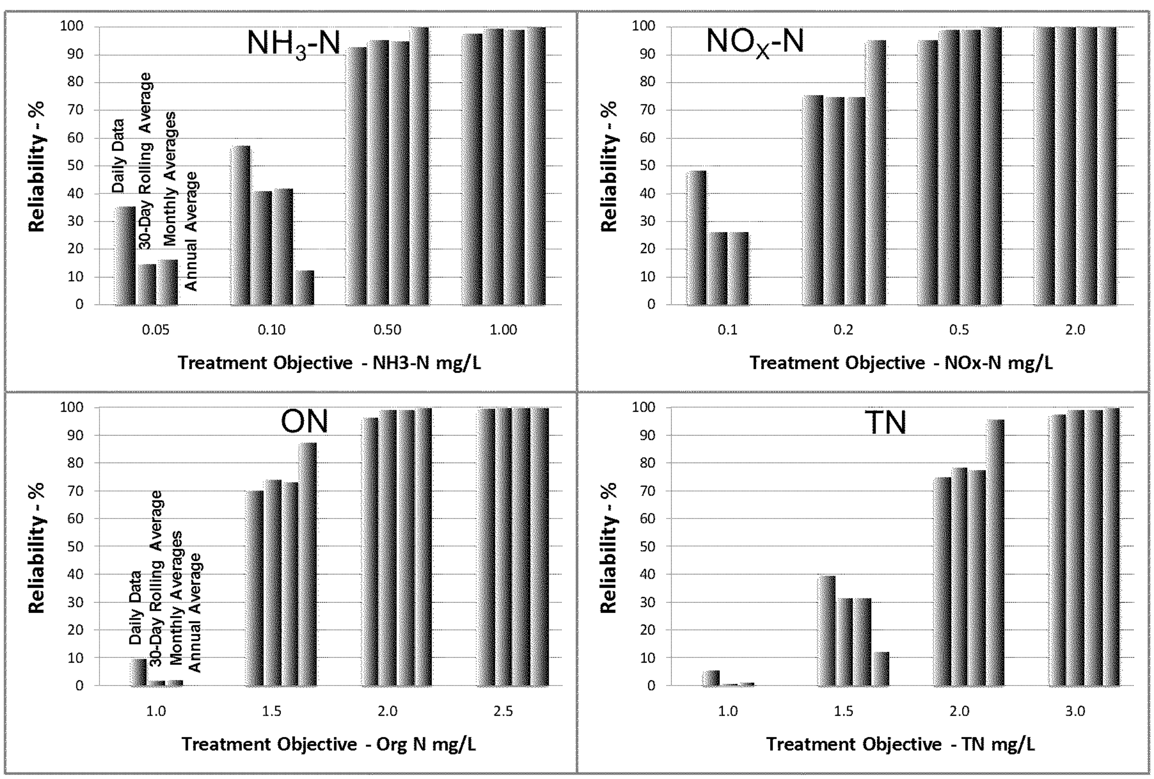

Figure 3-6. Reliability Summary for TMWRF.

Note that the Reliability Calculations Assume that the Data are Log-normally Distributed.

3.4.2 River Oaks, FL

The original 3.0 MGD River Oaks Advanced Wastewater Treatment Plant (ROAWTP) began operation in 1975 as an activated sludge plant with denitrification filters. As a result of the population growth of the late 1970s and early 1980s the ROAWTP was severely overloaded, operating at times double its capacity. In order to accommodate growth, Hillsborough County authorized developers to construct small package plants to serve new subdivisions. This made operating its wastewater system efficiently and controlling effluent quality very difficult. Hillsborough County hired Brown and Caldwell in 1982 to develop a plan that would effectively manage wastewater in Northwest Hillsborough County. Due to the difficulties with modifying an existing operating plan, a three-phase program was initiated to increase the design capacity from 3 MGD to 12 MGD. Phase I included a new suspended growth denitrification system that, at that time, was one of the largest of its kind in the U.S. When completed in 1987; the capacity was unchanged but the added system removed some of the hydraulic issues and improved overall effluent quality. Phase II included the renovation of the existing 1975 treatment units, adding a new headworks, primary clarifiers, and four additional filters. When completed in 1988, this phase of expansion increased the design capacity from 3 MGD to 7.5 MGD. The final Phase III brought the overall design capacity to 12.0 MGD with the addition of a flow equalization tank. In 2001, an effluent pumping station and 5 MG ground storage tank were added to provide the county residents with reclaimed water for irrigation.

The ROAWTP is capable of achieving annual average treatment levels as low as 3.1 mg/L cBOD and suspended solids, 1.9 mg/L TN, and 0.6 mg/L TP. At the time of its design, these were some of the most stringent limits in the U.S. As a result of the Grizzle-Figg law, the U.S. EPA and Florida Department of Environmental Protection relaxed the limits to 5.0 mg/L cBOD and suspended solids, 3.0 mg/L TN, and 1.0 mg/L TP. Table 3-10 summarizes the current effluent limitations. For the past 20 years, this treatment process has provided some of the region's highest quality treatment of wastewater.

Table 3-10. Current NPDES Permit Limits as of October 2008 at the River Oaks AWWTP.

Parameter	Annual Average	Monthly Average	Weekly Average	Single Sample
Flow (MGD)	10.0	N/A	N/A	N/A
cBOD (mg/L)	5.0	6.25	7.5	10.0
TSS (mg/L)	5.0	6.25	7.5	10.0
TN (mg/L)	3.0	3.75	4.5	6.0
TP (mg/L)	1.0	1.25	1.5	2.0
DO (mg/L)	N/A	N/A	N/A	5.0

Note:
a. N/A: Data not available or applicable.

The ROAWTP has a permitted capacity of 10.0 MGD and is a two-stage system. The first stage is a biological treatment process that includes suspended growth carbonaceous biochemical demand removal and nitrification. The second stage is a suspended growth denitrification system that utilizes methanol as a carbon source. Figure 3-7 illustrates the process flow schematic and Table 3-11 contains the raw influent wastewater design parameters and average raw influent concentrations. Primary, secondary, and tertiary sludge and scum are pumped to a 10,000 gallon sludge blend tank where it is then pumped to an offsite Biosolids Management Facility for further treatment and disposal.

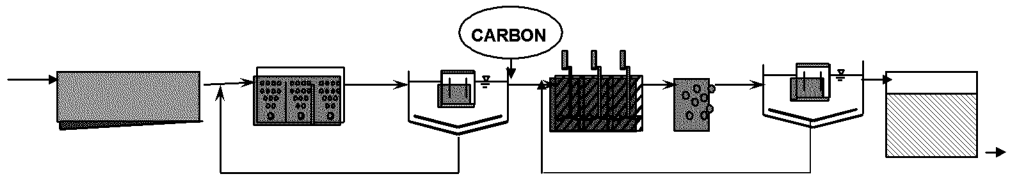

Figure 3-7. River Oaks Process Flow Diagram.

Table 3-11. Design and Average Raw Influent Concentrations and Percent of Design Loads for the ROAWTP from April 2005 Until March 2008.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	10	7.7	77
$cBOD_5$ (mg/L)	200	194	75
TSS (mg/L)	275	297	83
Ammonia (mg/L)	22	33.6	118
TKN (mg/L)	31	44.7	111
TP (mg/L)	9	5.8	50

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).

3.4.3 Western Branch, WSSC, MD

The Western Branch wastewater treatment plant (WBWWTP) utilizes a three sludge BNR process and is owned and operated by the Washington Suburban Sanitary Commission (WSSC). The system is comprised of four parallel trains, each with three separate activated sludge processes in series: high rate activated sludge (HRAS), nitrification activated sludge (NAS), and denitrification activated sludge (DNAS). The HRAS process provides carbonaceous oxidation, followed by the NAS process for ammonia oxidation. The DNAS process is next and reduces nitrate to nitrogen gas with methanol addition followed by an aerated nitrogen stripping channel. Each activated sludge process is equipped with intermediate clarifiers making the plant a three sludge system. Phosphorus removal is achieved by alum addition and tertiary filtration. The filter effluent is disinfected by UV disinfection prior to discharge to the Western Branch of the Patuxent River. The waste activated sludge (WAS) from all three stages is thickened by dissolved air flotation, dewatered by centrifuges, and is then incinerated by multiple hearth furnaces. Figure 3-8 illustrates the overall process flow diagram for the facility. Table 3-12 shows the raw wastewater influent design characteristics and average raw influent concentrations. Table 3-13 shows the NPDES permit limits for the WBWWTP from September 1, 2005 to August 31, 2010.

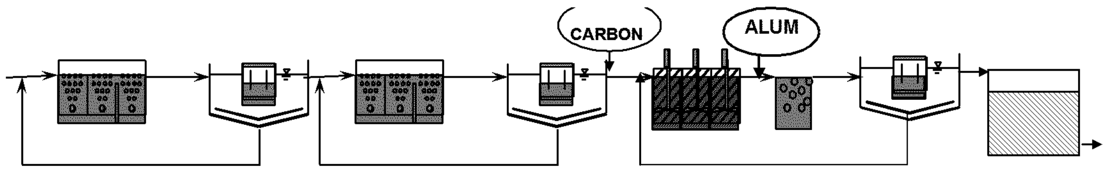

Figure 3-8. Western Branch Process Flow Diagram.

Table 3-12. Design and Average Raw Influent Concentrations and Percent of Design Loads for the WBWWTP from January 2005 Until December 2008.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	30	23	77
BOD_5 (mg/L)	200	N/A	N/A
TSS (mg/L)	200	252	97
TKN (mg/L)	35 [b]	25.5	56
TP (mg/L)	9	3.8	32
Temperature (°C)	N/A	18.1	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Raw influent design value as TN. Percent of design assumes average raw influent TKN is approximately equal to TN.
d. N/A: Data not available or applicable.

Table 3-13. NPDES Permit Limits from September 2005 to August 2010 at the Western Branch WWTP.

Effluent Characteristic	Monthly (kg/d)	Weekly (kg/d)	Monthly (mg/L)	Weekly (mg/L)
BOD_5 (4/1 – 10/31)	1000	1600	9.0	14
BOD_5 (11/1 – 3/31)	3400	5100	30	45
TSS	3400	5100	30	45
TP	110	N/A	1.0	N/A
TN (4/1 – 10/31)	340	510	3.0	4.5
Ammonia (4/1 – 10/31)	170	260	1.5	N/A
Ammonia (11/1 – 3/31)	630	N/A	5.5	N/A

Note:
a. N/A: Data not available or applicable.

3.4.4 Scituate, MA

The Scituate WWTP is located in Plymouth County along the coast of Massachusetts Bay, approximately 20 miles south of Boston. Scituate is a bedroom community; its only industry is a concrete pipe manufacturer. Only about 40% of the town's population has sanitary sewers. The WWTP was operational in 1967 designed to treat an average daily flow of 1.0 MGD and a peak flow of 2.5 MGD utilizing the extended aeration mode of the activated sludge process. The secondary effluent was discharged to sand filtration beds (SFB); solids were stored in sludge holding tanks when the drying beds were full or in inclement weather.

The hydraulic capacity of the SFB was exceeded in 1975 (infiltration/inflow [I/I] problem) frequently overflowing and entering a tidal ditch which is a tributary of the Herring River. In 1980 an emergency overflow pipe was constructed in the SFB to direct excessive flows to the tidal ditch so as to protect the embankment surrounding the SFB. A septage receiving station and dewatering building with 1.5-meter belt filter presses (BFP) were added during an upgrade in 1980 and at the same time the existing sludge holding tanks were converted to aerobic digesters.

In 1987 the Massachusetts Department of Environmental Protection (MADEP) issued Administration Order (AO) 698, which imposed a new sewer connection moratorium in Scituate due to the excessive flows entering the tidal ditch. A draft facilities plan for wastewater management was published in 1993 addressing the requirements of the AO, which evaluated a number of alternative scenarios for wastewater treatment and discharge and established priority areas for future sewer expansion. In 1994 the MADEP updated the AO 698 to an Administrative Consent Order negotiated with the Town of Scituate; which continued the moratorium on sewer connections and included a schedule for planning, design, and construction of a Scituate WWTP upgrade.

Due to a regulatory conflict between federal and state agencies, the Scituate WWTP did not receive its first NPDES permit until 1997. That permit had a TN limit of 39.5 lbs./day. The renewed permit which took effect June 1, 2006 had an increased TN limit of 53 lbs./day. In the opinion of MADEP the increase would not result in a lowering of water quality in the receiving stream due to the refractory, soluble organic nitrogen portion (not removed in the treatment process) that is considered approximately 1.0-1.5 mg/L. The MADEP had suggested changing the permitting basis to total inorganic nitrogen (TIN) (the town's consultant had highly sought this), but the Environmental Protection Agency instead decided to raise the TN limit.

The moratorium on sewer connections was lifted in 2004 and a six-phase sewer expansion program started with construction of new sewers (Phase I 333 and Phase II 255 eligible connections) in 2005 and 2006. An increase in summer population adds loading to the WWTP while normal dry weather decreases I/I.

The most recent upgrade was completed in 2000 increasing the design of the WWTP from 1.0 MGD up to 1.6 MGD along with upgrading secondary treatment to an advanced treatment capable of nitrogen removal (nitrification/denitrification). The secondary aeration system (without anoxic zones) was doubled in size to ensure complete nitrification during design loadings in cold weather and mechanical surface aerators were replaced with fine bubble diffused aeration. A third clarifier was added, the use of UV light replaced chlorination for disinfection, post aeration tanks were constructed prior to discharge, and two new 1.5-meter BFPs replaced the existing BFP. A process flow schematic is depicted in Figure 3-9 and the raw influent wastewater design parameters and average raw influent concentrations are shown in Table 3-14.

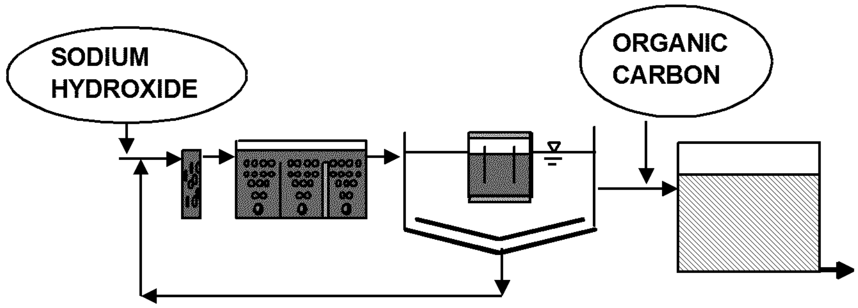

Figure 3-9. Scituate Process Flow Diagram.

Table 3-14. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Scituate WWTP from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	1.6	1.27 [b]	79
BOD_5 (mg/L)	222	130	46
TSS (mg/L)	202	167	66
TKN (mg/L)	22.9	20.5	71
Temperature (°C)	N/A	14.4 [a]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

Raw wastewater flows into the headworks via a 36-inch interceptor sewer to preliminary treatment comprised of a mechanical bar screen and a manually cleaned bypass bar rack before dropping into the influent wet wells. Screened influent is then lifted up by the influent pumps to the aerated grit tank, from there flowing into a distribution tank mixing with RAS from the clarifiers and at that point soda ash is added for alkalinity and pH control. The mixed liquor (ML) then can be distributed between the existing (old) aeration tanks 1, 2, and 3 and the new aeration tank 4; a three-compartment aerobic selector zone fronts both systems. The ML then flows through three 45ft diameter clarifiers, secondary effluent gravity flows with methanol addition to the intermediate wet wells in the filter building and is pumped up to the Tetra Denite□ Filters.

The four parallel filters are down flow biofilm reactor type, which denitrify the secondary effluent, adjacent to them is the clearwell for storage of filter effluent, which is used for backwashing and bumping (nitrogen gas release). A mud well is also provided for storage of dirty backwash water; the backwash water is pumped back to the headworks. The denitrified effluent continues through to the UV channel, which uses medium pressure high intensity lamps for disinfection, then flows on to the post aerations tanks used to re-aerate the effluent to a dissolved oxygen concentration of 6.0 mg/L and finally flows through a 9-inch Parshall Flume to the tidal ditch. Table 3-15 and Table 3-16 provide NPDES permit limits.

Table 3-15. NPDES Permit Limits Prior to June 2006 at the Scituate WWTP.

Effluent Parameter	Monthly Average	Weekly Average
Flow (MGD)[a]	N/A	N/A
$cBOD_5$ (mg/L)	10	15
TSS (mg/L)	10	15
DO (mg/L)	Greater than 6.0	
TN (lbs/day)[b]	39.5	N/A

Note:
a. 1.6 MGD is the 12-month moving average limit.
b. 39.5 lbs/day TN is the 12-month moving average limit.
c. N/A: Data not available or applicable.

Table 3-16. NPDES Permit Limits After June 2006 at the Scituate WWTP.

Effluent Parameter	Monthly Average (lbs/day)	Monthly Average (mg/L)	Weekly Average (mg/L)
Flow (MGD) [a]	N/A	1.6	N/A
$cBOD_5$	133	10	15
TSS	133	10	15
DO	N/A	≥6.0	N/A
TN (lbs/day) [b]	53	4.0	N/A

Note:
a. 1.6 MGD is the 12 month rolling average.
b. 53 lbs/day TN is the 12 month rolling average.
c. N/A: Data not available or applicable.

3.4.5 Tahoe-Truckee Sanitation Agency, CA

The Tahoe-Truckee Sanitation Agency (T-TSA) owns the Martis Valley Wastewater Treatment Plant which is an advanced municipal wastewater reclamation facility located in Truckee, California. T-TSA receives and provides tertiary-level treatment to approximately 17,000 m^3/d (4.6 MGD) of municipal wastewater on an annual average basis. The facility's treatment processes include primary and secondary treatment, including biological phosphorus and nitrogen removal, effluent filtration, and disinfection by chlorination. The facility injects the chlorinated effluent into a subsurface disposal field, which is located approximately one mile from the confluence of the Truckee River and Martis Creek, for further effluent polishing.

T-TSA's discharge requirements are very stringent to preserve the pristine nature of the Truckee River and Martis Creek. The Truckee River flows approximately 70 miles from its source at Lake Tahoe to Pyramid Lake, which has no outlet. The lack of an outlet results in the buildup of total dissolved solids (TDS) in the lake over time. T-TSA's facility, including its disposal field, must meet TN limits of 3.0 mg/L on an annual average basis and 2.0 mg/L over the summer months (May 1st through October 31st), and a TP monthly average limit of 0.3 mg/L. T-TSA's permit limits prior to subsurface disposal and after the soil aquifer treatment (SAT) system are provided below in Table 3-17 and Table 3-18. Historically, the facility removed the majority of the TN using an ion exchange process. This process was effective at removing TN (in the form of NH_4-N). However, TDS were released into the final effluent as a byproduct of the process.

Table 3-17. Current NPDES Permit Limits Prior to Subsurface Disposal as of June 2010 at T-TSA.

Constituent	Monthly Average	Maximum
Suspended Solids (mg/L)	10	20
Turbidity (NTU)	N/A	10
TP (mg/L)	0.8	1.5
COD (mg/L)	45	60
TN (mg/L)	9	12

Note:
a. N/A: Data not available or applicable.

Table 3-18. Current NPDES Effluent Limits in Monitoring Well 31 as of June 2010 at T-TSA.

Constituent	Monthly Average	Maximum
COD (mg/L)	15	40
Un-ionized Ammonia-N (mg/L)	N/A	0.20
TP (mg/L)	0.3 [a]	N/A
Fecal Coliform Bacteria (MPN/100mL)	N/A	2.2 [b]
TN (mg/L)		
May 1 – October 31	2.0	N/A
January 1- December 31	3.0 [a]	N/A

Note:
a. Annual average.
b. Mean of 7-day average.
c. N/A: Data not available or applicable.

In December 1997, T-TSA began investigating alternative nitrogen removal processes that would meet stringent TN requirements and not contribute TDS to the final effluent. The selected process had to be capable of meeting both TN and TDS criteria and also had to operate over a wide range of temperatures and flows. The influent temperature of the facility's wastewater typically varies from 7 to 20°C and the influent flow rate typically varies from 11,300 to 30,300 m^3/d (3 to 8 MGD). T-TSA selected a biologically active filter (BAF) system to accomplish its objectives because it is a technology that has been used to achieve a high degree of nitrogen removal in cold climates (Jonsson, 2004).

BAFs utilize granular or spherical-shaped media to provide a large surface area-to-volume ratio for fixed-film microbial growth. The large surface area per unit volume results in BAFs having a small footprint compared to similar wastewater treatment processes (Stephenson et al., 1993). Furthermore, BAFs are capable of removing TSS as well as nutrients, such as BOD and nitrogen (Stephenson et al., 1993). Recently, BAFs have been utilized by several municipal wastewater treatments plants for denitrification (Fred and Kiiskinen, 2005; Jonsson, 2004; Pearson et al., 2008). These systems have achieved high TIN removals and moderate TSS and OP removals. A process flow diagram is provided in Figure 3-10 and the raw influent wastewater design parameters and average influent concentrations are provided in Table 3-19.

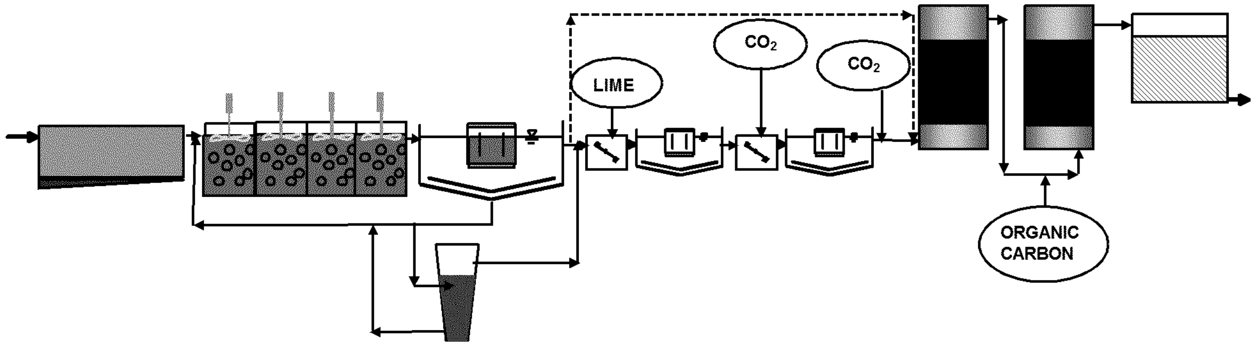

Figure 3-10. T-TSA Process Flow Diagram.

Table 3-19. Design and Average Raw Influent Concentrations and Percent of Design Loads for T-TSA from January 2007 Until December 2009.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	8	4.2	53
BOD_5 (mg/L)	200	225	59
COD (mg/L)	N/A	516	N/A
TSS (mg/L)	170	202	62
TKN (mg/L)	43	39.3	48
TP (mg/L)	N/A	5.9	N/A
Temperature (°C)	N/A	12.9 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

To help ensure that stringent TIN requirements of 2.0 mg/L for summer months and 3.0 mg/L for winter months were met with the full-scale system, T-TSA conducted two years of testing of a pilot-scale nitrification and denitrification BAF unit. The pilot-scale testing included investigations of operating strategies to achieve the effluent nitrogen requirements under various conditions, including transient nitrogen loads, aeration limitations, temperature fluctuations, and different methanol dosing ratios. The results generated from the pilot-scale study were used to establish the operating parameters for start-up and normal operation of the full-scale facility. T-TSA commissioned a full-scale Krüger BIOSTYR® nitrification and denitrification BAF system in August 2006. The system was designed to treat a maximum week flow of 45,400 m^3/d (12 MGD) down to TIN concentrations of 2.0 mg/L and 3.0 mg/L for summer and winter periods, respectively.

WAS from the secondary clarifiers is pumped to gravity thickeners. The thickened WAS, primary solids, and scum are separately fed to a thermophilic digester. Effluent from the thermophilic digester is split between two parallel mesophilic digesters. Effluent from these digesters is combined in a final mesophilic digester with a gas holding cover. From the final digester, digested sludge is withdrawn and dewatered with centrifuges and trucked offsite for disposal. Some of the chemical solids produced are also blended into the centrifuges for dewatering. The remaining chemical clarifier sludge is gravity thickened and dewatered with a filter press followed by offsite disposal.

3.4.6 Eastern Water Reclamation Facility, FL

The Orange County Utilities Eastern Water Reclamation Facility (EWRF) provides advanced wastewater treatment for residential, commercial, and industrial customers in Orange County's Eastern Service Area in east central Florida. The EWRF is currently permitted for 19.0 MGD annual average daily flow (AADF) of total treatment capacity. Current flows to the facility average approximately 17.4 MGD. Construction of the Eastern WRF has occurred in several phases. The treatment and reuse system was expanded each time. The original Phase I facility replaced five existing package plants and provided additional capacity for new developments in the service area. It began operation in February 1984 as a 2.5 MGD plant utilizing a Modified Ludzack-Ettinger (MLE) process incorporating a Carrousel™ oxidation ditch for partial denitrification. A 6 MGD Phase II expansion was completed in August 1984 and the facility was upgraded to produce advanced wastewater treatment (AWT) quality effluent using the five-stage Bardenpho/Carrousel™ for biological removal of nitrogen and phosphorus. In January 1988, the plant's capacity was further increased with the construction of the 6 MGD Phase III facilities. Another phase of the Eastern WRF's expansion occurred in 1995 with the rerate construction project. This project expanded the capacity of the Phase I/II treatment plant to 9.0 MGD and the capacity of the Phase III facilities to 10 MGD for a total combined permitted capacity of 19 MGD. The County has started construction to increase the permitted wastewater treatment capacity to 24 MGD AADF with provisions for re-rating the treatment capacity at some point in the future. Ultimately, the plant will be expanded to a capacity of approximately 40 MGD in order to accommodate future wastewater flows. The reuse system consists of rapid infiltration basins, power plant reuse, wetlands application and public access reuse with permitted annual average or agreement capacities of 2.5 MGD, 13 MGD, 6.2 MGD and 2.4 MGD, respectively. WAS is dewatered with belt filter presses and sent to a Central Processing Facility for additional treatment and ultimately land application. A flow diagram of the EWRF is shown in Figure 3-11. The plant must meet Florida AWT effluent standards, which are 5 mg/L BOD_5 and TSS, 3 mg/L TN, and 1 mg/L TP on an average annual basis for wetlands reuse. The permit limits for wetlands reuse are provided below in Table 3-21. The raw influent wastewater design parameters and average influent concentrations are provided in Table 3-20.

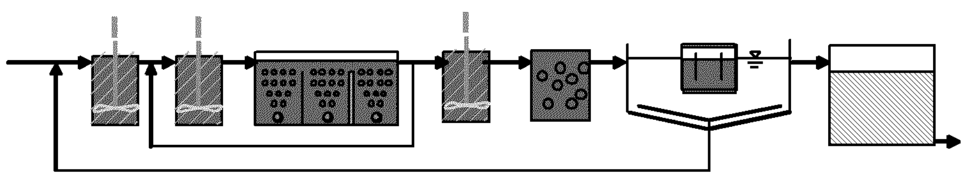

Figure 3-11. EWRF Process Flow Diagram.

Table 3-20. Design and Average Raw Influent Concentrations and Percent of Design Loads for the EWRF from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	19	16.9	89
$cBOD_5$ (mg/L)	190	162	76
TSS (mg/L)	190	151	71
TKN (mg/L)	35	N/A	N/A
TP (mg/L)	10	4.6	41
Temperature (°C)	N/A	19.6 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

Table 3-21. NPDES Permit Limits for Wetlands Reuse from March 2004 to March 2009 at the EWRF.

Parameter	Annual Average	Monthly Average	Weekly Average
$cBOD_5$ (mg/L)	5.0	8.0	9.6
TSS (mg/L)	5.0	8.0	9.6
TN (mg/L)	3.0	5.0	6.0
TP (mg/L)	1.0	2.0	2.4

3.4.7 Parkway, WSSC, MD

The Parkway WWTP is a 7.5 MGD facility in Laurel, MD which is owned and operated by the WSSC. A process flow diagram is shown below in Figure 3-12 and the raw influent wastewater design parameters and average influent concentration are shown in Table 3-22. The plant is located in the Prince George's County portion of the City of Laurel. (Portions of the City of Laurel that lie in Howard County are serviced by the 18 MGD Little Patuxent WRF, and portions of the City of Laurel that lie in Anne Arundel County are serviced by the 2.5 MGD Maryland City WRF.) Despite the urban location, the Parkway WWTP is fortunate to be buffered by the Baltimore-Washington Parkway to the north-west, and there are forested buffers on the remaining three sides.

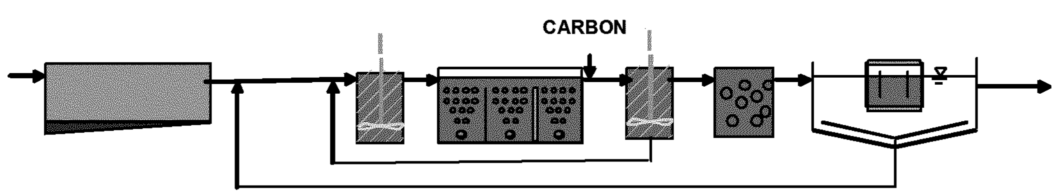

Figure 3-12. Parkway Process Flow Diagram.

Table 3-22. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Parkway WWTP from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design
Flow (MGD)	7.5	5.7 [b]	76
BOD_5 (mg/L)	192	220	87
TSS (mg/L)	280	354	96
TKN (mg/L)	29	24.5	64
Ammonia (mg/L)	18	15.7	66
TP (mg/L)	5	4.3	65
Temperature (°C)	N/A	19.4 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

The Parkway WWTP was originally constructed as a 2.4 MGD trickling filter plant in 1959. In 1971 it was expanded to a 7.5 MGD activated sludge plant. The activated sludge process only included what is currently referred to as Aeration Basin #1, and it polished the trickling filter effluent by providing nitrification. In 1992, the plant was upgraded to a BNR facility, designed to meet 7.0 mg/L TN on a seasonal basis; the trickling filters were abandoned and the flow was split 40% to Aeration Basin #1, and the remaining 60% to the newer Aeration Basin #2.

Raw influent is received at the plant via a 33 inch trunk sewer and a 48-inch trunk sewer. The current liquids process consists of fine screening, vortex grit removal, primary clarification, activated sludge treatment via the two parallel 4-stage Bardenpho processes, secondary clarification, sodium hypochlorite addition for disinfection, sodium bisulfite addition for de-chlorination, post aeration, and final effluent discharge to the Patuxent River. There is flexibility to add alum for phosphorus removal, and sodium hydroxide for pH adjustment, though both are rarely used. See Table 3-23 below for discharge limits.

Table 3-23. NPDES Permit from September 2005 to August 2010 at the Parkway WWTP.

Parameter	Monthly Average	Max Week Average
BOD_5 (mg/L)	20 summer / 30 winter	30 summer / 45 winter
TSS (mg/L)	30	45
Ammonia-N (mg/L)	2 summer / 7.7 winter	N/A
TN (mg/L)	7.0 (4/1 – 10/15)	11.0 (4/1 – 10/15)
TP (mg/L)	1.0	1.5

Note:
a. N/A: Data not available or applicable.

The current solids process consists of gravity thickeners for primary sludge, use of gravity belt thickeners (GBTs) for waste activated sludge (WAS), blending of the thickened sludges, centrifuge dewatering, and post lime stabilization. Centrifuge dewatering and post-lime stabilization is accomplished using either the "old side" or the "new side". The "old side" consists of dewatering via three Sharples PM-5000 centrifuges (1959 era, average 15-17% cake); the cake is pumped to Leopold Plowblenders for lime-stabilization, and the stabilized biosolids are belt conveyed directly to trailers, and hauled to land application sites. The "new side" consists of dewatering via a Sharples DS-706 centrifuge (1996 era, average 20-22% cake); the cake is conveyed to a pugmill for lime stabilization, and the stabilized biosolids are then conveyed to a silo for temporary storage before being hauled to land application sites. The "new side" was modified in 2005 and relies heavily upon a series of shaftless screw conveyors (several inclined and one which is vertical); due to many unresolved problems, the "new side" has yet to prove itself as reliable, and the "old side" is most heavily relied upon.

3.4.8 Piscataway, WSSC, MD

The Piscataway WWTP was first constructed in 1965 as a 5 MGD secondary WWTP that was at capacity shortly after starting operations. In 1972 the plant was expanded to a 30 MGD secondary treatment plant. Through a series of staged upgrades, the Piscataway WWTP was converted to an AWT plant to include nitrification, chemical phosphorus removal with alum, and tertiary filtration.

The major plant process include, pumping, grit and fine screenings removal, primary clarification, intermediate flow splitting and pumping, biological treatment, chemical addition (alum) for phosphorus removal, secondary clarification, tertiary filtration with dual media filters (anthracite over sand), UV disinfection, co-gravity thickening of primary sludge and WAS, lime stabilization of thickened biosolids and BFP dewatering followed by land application and beneficial reuse of biosolids on agricultural fields.

In July 2000, the plant was converted to a BNR facility using the step feed process with two parallel trains and each train having two parallel treatment basins. No additional process reactor or clarifier volume was constructed as part of the project. Each biological reactor basin has multiple passes (five passes for each train 1 basins and four passes for each train 2 basins). Primary effluent is fed into the anoxic zone, the first four passes of the train 1 basins and the first three passes of the train 2 basins. The rbCOD in the primary effluent acts as a carbon source for the denitrification process. The last pass in each basin is substantially anoxic and is not fed primary effluent. A small aerobic section is in located at the end of the final pass to strip nitrogen gas and nitrify any ammonia that may have been released through decay in the reactors. The step feed biological reactors are equipped with medium fine bubble flexible rubber membrane diffusers in a complete floor cover to supply air to the aerobic zones. They include drop header valves to allow complete shut off of air to the anoxic zones. DO probes are located in the center of the aerobic zones and supply a feedback signal to a control loop that controls airflow to the main headers and actuates control valves. The anoxic zones are equipped with submersible mixers that can be adjusted to specific depths or angular orientation to keep the biomass suspended. RAS is sent to the head of the first pass in each of the four treatment basins. The last anoxic zones in each treatment basin are equipped with in-situ nitrate probes that provide continuous monitoring of nitrate levels.

After leaving the biological reactors liquid alum (approximately 48% aluminum sulfate solution) is added in turbulent zones prior to each of the secondary clarifiers. There is one secondary clarifier per reactor basin. The train 1 secondary clarifies are 160-foot diameter units with a bottom suction header design and train 2 secondary clarifiers are 200-foot diameter sludge siphon design. Both sets of clarifiers have 13-foot side water depths with full diameter surface skimming arms.

The overflow from all four secondary clarifiers is recombined and flows to the tertiary polishing filter system. This system consists of twelve 27-foot x 27-foot dual media filters (anthracite over sand) with a filtration media bed depth of 36 inches and a gravel support bed and Wheeler under drains. Backwash is performed with water only and includes surface water scour.

After tertiary filtration, the filter effluent goes through UV disinfection and is pumped via Archimedes screw pumps to a 3.3 mile gravity discharge pipe and conveyed to the Potomac River. Figure 3-13 and Table 3-24 below provides the process flow diagram and raw influent wastewater design parameters and average influent concentrations, respectively. Table 3-25 contains some of the permit limits for Piscataway WWTP.

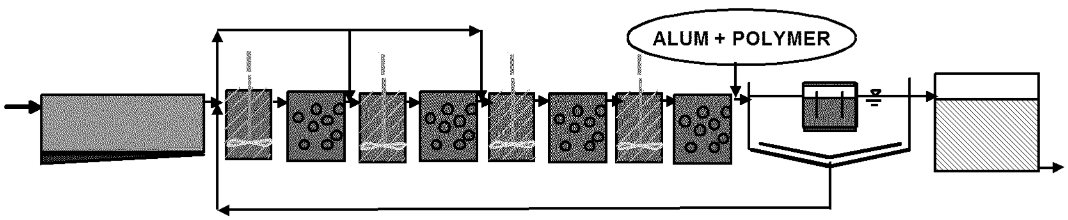

Figure 3-13. Piscataway Process Flow Diagram.

Table 3-24. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Piscataway WWTP from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	30	20.8 [b]	69
BOD_5 (mg/L)	132	105	55
TSS (mg/L)	144	125	60
TKN (mg/L)	N/A	21.4	N/A
Ammonia (mg/L)	16	17.8	77
TP (mg/L)	10	2.7	19
Temperature (°C)	N/A	17.3 [b]	N/A

Note: a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

Table 3-25. NPDES Permit Limits from August 2003 to July 2008 at the Piscataway WWTP.

Parameter	30-Day Average	7-Day Average
Flow (MGD)	30	N/A
BOD_5 (mg/L)	30	45
TSS (mg/L)	30	45
TP (mg/L)	0.18	N/A
TP (lbs/yr)	16,438	N/A
TN (mg/L)	8	N/A
TN (lbs/yr)	513,800	N/A

Note: a. N/A: Data not available or applicable.

Underflow from the secondary clarifiers is returned to the reactor basins as RAS and a small amount is wasted on a continuous basis. The WAS and the primary clarifier underflow are combined and is co-thickened in gravity thickeners. The underflow from these first stage thickeners is mixed with a slaked lime suspension and the stabilized biosolids are held at an elevated pH for 24 hours. The biosolids are then dewatered with belt presses and then land applied at agricultural sites as Class B biosolids. All recycle streams (filter backwash, belt press filtrate, gravity thickener overflow) return back to the head of the plant with some of the filter backwash being returned to the head of the train 2 reactors.

3.4.9 Fiesta Village, FL

The Fiesta Village Advanced Wastewater Treatment Plant is located in Fort Myers, Florida and has a capacity of 5.0 MGD. The plant includes an oxidation ditch type biological treatment system that combines suspended growth $cBOD_5$ removal and simultaneous nitrification/denitrification followed by an attached growth denitrification system (tertiary filters) with methanol addition.

Figure 3-14 presents the plant process flow schematic. Influent passes through the influent flow meter on the force main, through a link type screen and through a dual aerated grit removal system. Aeration ditches number 1 and number 2 consist of anoxic zones and aerated zones. The influent wastewater along with RAS enters the oxidation ditches. Stationary brush type aerators are used in these basins to provide oxygen and mixing for the oxidation of cBOD. Nitrification occurs in this stage. Alum is fed at the ditch outlet, to two secondary clarifiers. The next part of the process is accomplished by four tertiary denitrification filters followed by re-aeration, two chlorine contact chambers then on to dechlorination and then to reuse or discharge. Wasted solids are aerated in two digesters are either dewatered on site or hauled to the Fort Myers Beach biosolids treatment facility for dewatering. In either case the biosolids are taken to the Lee County landfill for disposal.

Table 3-26 contains the raw influent wastewater design parameters and average influent concentrations.

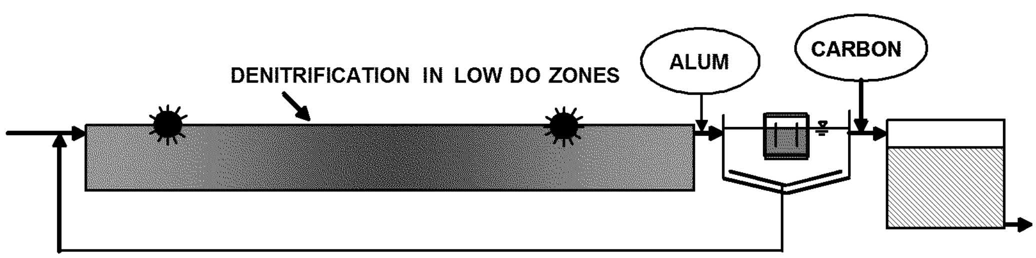

Figure 3-14. Fiesta Village Process Flow Diagram.

Table 3-26. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Fiesta Village AWTP from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	5	3.2	64
BOD_5 (mg/L)	150	147	63
TSS (mg/L)	225	233	66
TKN (mg/L)	60	N/A	N/A
Ammonia (mg/L)	40	N/A	N/A
TP (mg/L)	6	N/A	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. N/A: Data not available or applicable.

The Fiesta Village Wastewater Treatment Plant is currently operating under FDEP Permit Number FLO039829; expiration date September 10, 2008. Effluent limits are identified in Table 3-27 and Table 3-28. The plant has a permitted capacity of 5.0 MGD based on the AADF.

Table 3-27. NPDES Permit Limits to the Caloosahatchee River from September 2003 to September 2008 at the Fiesta Village AWTP.

Parameter	Annual Average	Monthly Average	Weekly Average	Single Sample
Flow (MGD)	5.0	N/A	N/A	N/A
$cBOD_5$ (mg/L)	20.0	25.0	40.0	60.0
TSS (mg/L)	20.0	30.0	45.0	60.0
TN (mg/L)	3.0	3.0	4.5	6.0
TN (lbs/day)	N/A	124.9	N/A	N/A
TP (mg/L)	0.5	0.5	0.75	1.0
TP (lbs/day)	N/A	20.8	N/A	N/A

Table 3-28. NPDES Permit Limits to the Public Access Reuse System from September 2003 to September 2008 at the Fiesta Village AWTP.

Parameter	Annual Average	Monthly Average	Weekly Average	Single Sample
Flow (MGD)	3.158	N/A	N/A	N/A
$cBOD_5$ (mg/L)	20.0	30.0	40.0	60.0
TSS (mg/L)	N/A	N/A	N/A	5.0

3.5 Phosphorus Removal Plants

3.5.1 Clark County, NV

The Clark County Water Reclamation District's Central Plant has been serving the unincorporated areas of the Las Vegas Valley, since the early 1950s. In the late 1970s, CCWRD began construction of its AWT plant using chemical precipitation for phosphorus removal. Initially the phosphorus limit was 1 mg/L. Since then, a total mass daily load has been established and the discharge requirement is now 174 pounds per day of TP or about 0.20 mg/L at present flows just under 100 MGD. The total mass daily load of phosphorus is enforced based on a maximum month condition from March through October. With the implementation of the total mass daily load, the activated sludge process of the Central Plant was converted to biological phosphorus removal in the mid-1990s. A simplified schematic flow diagram is shown in Figure 3-15. The plant currently meets its effluent TP limit using a combination of chemical precipitation in the primary clarifiers, biological phosphorus removal, and chemical polishing before tertiary filtration. The chemical polishing occurs in two parallel tertiary treatment facilities, the AWT plant and the Central Plant tertiary facility. CCWRD has two different and distinct tertiary treatment schemes and two separate and distinct discharge points into the Las Vegas Wash. The solids handling facilities consist of dissolved air flotation thickeners for WAS thickening. The combined mixture of primary sludge and WAS is dewatered and the filtrate sent back through the treatment plant. Table 3-29 contains the raw influent wastewater design parameters and average influent concentrations.

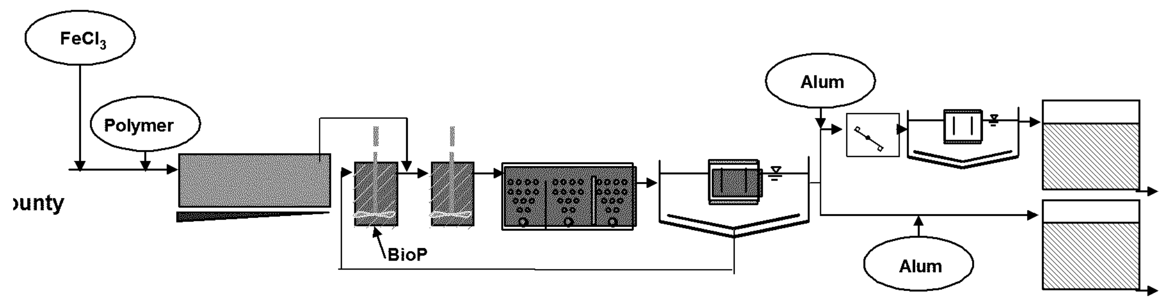

Figure 3-15. Clark County Process Flow Diagram.

Table 3-29. Design and Average Raw Influent Concentrations and Percent of Design Loads for CCWRD from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	110	89.6 [b]	90
BOD_5 (mg/L)	356	307	70
TSS (mg/L)	364	359	80
TKN (mg/L)	31	43.0	113
Ammonia (mg/L)	26.9	26.7	81
TP (mg/L)	6.2	6.2	81
Temperature (°C)	N/A	24.4 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

WERF

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Because of total mass daily load-based effluent limit for phosphorus, the numeric concentration of TP the plant has to meet in its effluent discharge continuously decreases with increasing flow. This is especially a concern at Clark County, because for quite some time, Las Vegas has been one of the fastest growing cities in the country. Since the early 2000s, CCWRD's service area has been growing at the rate of 4-5% per year or about 4-5 million gallons per day. Because of the rapid growth rate, there were concerns that the corresponding reduction in effluent discharge concentration limits for phosphorus could not be achieved with the use of conventional tertiary sand filters. Additionally, because of the drought conditions and the reduction in surface volume of Lake Mead, the Nevada Division of Environmental Protection was concerned that further reduction in the phosphorus total mass daily load might be needed for algae control. As a proactive measure, the CCWRD initiated an investigation to determine the lowest practically achievable effluent OP concentration with the current plant configuration, but with membranes replacing the tertiary sand filters.

The present NPDES permit limits are shown in Table 3-30. The four wastewater dischargers in the Las Vegas Valley have joined together to build an outfall in the middle of Lake Mead. This new discharge point will have the same TP limit as the total mass daily load, but will be enforced on an annual average basis.

Table 3-30. Current NPDES Permit Limits as of October 2008 at CCWRD.

Parameter	Monthly Average	Weekly Max	Daily
Flow (MGD)	150	N/A	N/A
BOD_5 (mg/L)	30	45	N/A
BOD_5 (kg/day)	17024	25535	N/A
TSS (mg/L)	30	45	N/A
TSS (kg/day)	17024	25535	N/A
Ammonia-N (mg/L)	0.41	N/A	511 (lbs/day) [a]
Ammonia-N (kg/day)	232	N/A	N/A
TP (mg/L)	0.14	N/A	176 (lbs/day) [a]
TP (kg/day)	79	N/A	N/A

Note:
a. Waste load allocation.
b. N/A: Data not available or applicable.

3.5.1.1 Example Phosphorus Removal Data Set – CCWRD

The Clark County Water Reclamation District experienced various operational issues from January 2005 through March 2008. In early 2006, a major construction project initiated that required major modifications to the aeration basins. Construction activities resulted in high effluent TP concentrations. Following to the construction project, operations staff tried to optimize phosphorus and nitrogen removal in aeration basins by changing operational parameters. During that period, TP removal suffered several times and higher effluent TP concentrations were measured. It was the conclusion of the plant manager that over 90% of the high effluent TP values were related to construction and operational changes that followed the upgrade activities.

Based on the entire data set, the facility has effluent daily and 30-day median TP values of 0.081 and 0.089 mg/L, respectively with maximum values of 1.17 mg/L (daily) and 0.20 mg/L (30-day).

Figure 3-16 through Figure 3-19 and Table 3-31 through Table 3-32 provide an example of the statistical summary compiled for the Clark County Water Reclamation District (CCWRD) treatment facility which has a current monthly TP permit limit of 0.20 mg/L at the design flow of 110 MGD and 0.14 mg/L at the monthly average flow of 150 MGD. Several observations are provided for these data:

- Figure 3-16: Comparing the TP 30-day rolling average to the 0.2 mg/L permit limit, it would appear that the treatment objective is being met.
- Figure 3-17: Probability plots suggest relatively good conformance with the log-normal distribution, with some deviation at high concentrations. As expected with averaging of the data set and attenuation of the upset events with longer averaging periods, better log-normal conformance is observed in Figure 3-17B, Figure 3-17C, and Figure 3-17D.
- Table 3-31 through Table 3-32 and Figure 3-18: If only one year of data was examined, the maximum value (Table 3-31 through Table 3-32) for the 30-day rolling average and monthly average data should be roughly equal to the 92nd percentile, which approximates the maximum month condition. Even though in this case 36 months of data was examined, considering the range shown in Figure 3-18 for the daily 90-95% probabilities, it appears that this is the case.
- Figure 3-19: CCWRD is quite reliable at the monthly TP permit limit of 0.20 mg/L. The OP reliability at this same concentration and lower is significantly higher, possibly suggesting that the majority of the effluent TP is comprised of non-OP phosphorus, either soluble or particulate. Figure 3-16 also seems to suggest that this is the case.

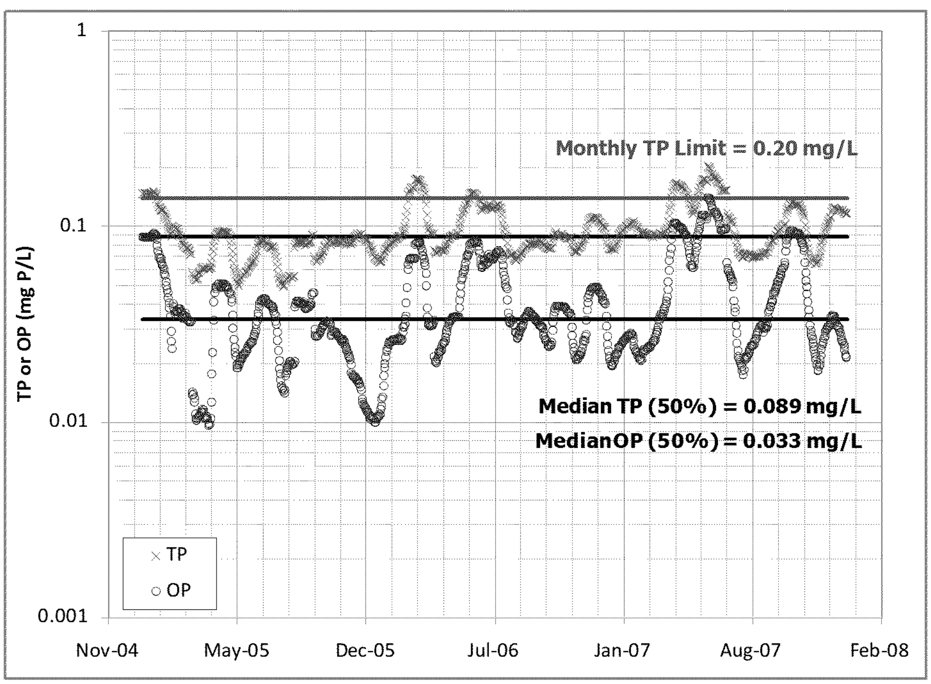

Figure 3-16. 30-Day Rolling Average Time Series Plot for CCWRD.

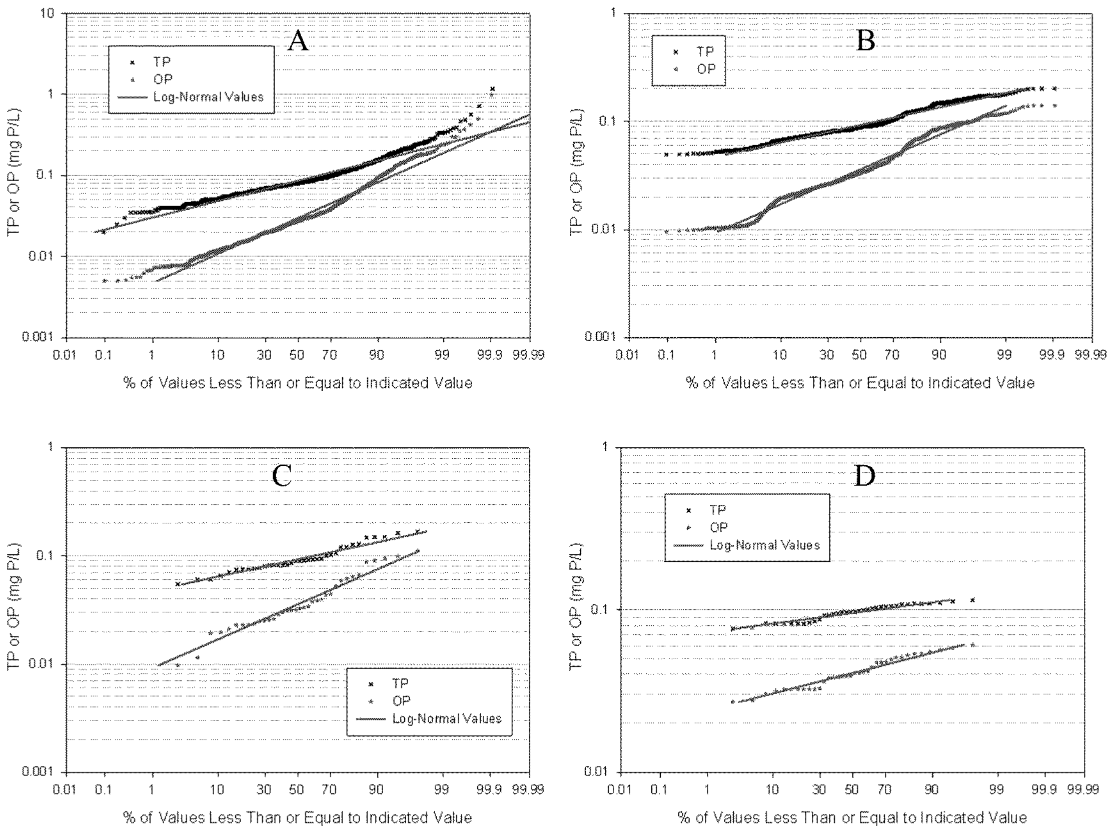

Figure 3-17. Probability Plots for CCWRD –
(A) Daily Data; (B) 30-day Rolling Average; (C) Monthly Averages; (D) Annual Average.

Table 3-31. Summary Statistics of Final Effluent TP for CCWRD.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	1088	1095	36	36
Mean	0.097	0.097	0.097	0.097
Geometric Mean	0.086	0.093	0.093	0.096
Std. Dev.	0.066	0.030	0.030	0.011
CoV	0.68	0.31	0.31	0.12
Skew	6.43	1.03	0.98	-0.22
Minimum	0.020	0.049	0.055	0.077
Maximum	1.17	0.20	0.17	0.12

Table 3-32. Summary Statistics of Final Effluent OP for CCWRD.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	1043	1095	36	36
Mean	0.043	0.043	0.042	0.042
Geometric Mean	0.030	0.036	0.036	0.041
Std. Dev.	0.055	0.026	0.026	0.0095
CoV	1.28	0.61	0.62	0.23
Skew	6.99	1.25	1.26	0.33
Minimum	0.0050	0.010	0.010	0.027
Maximum	0.99	0.14	0.11	0.061

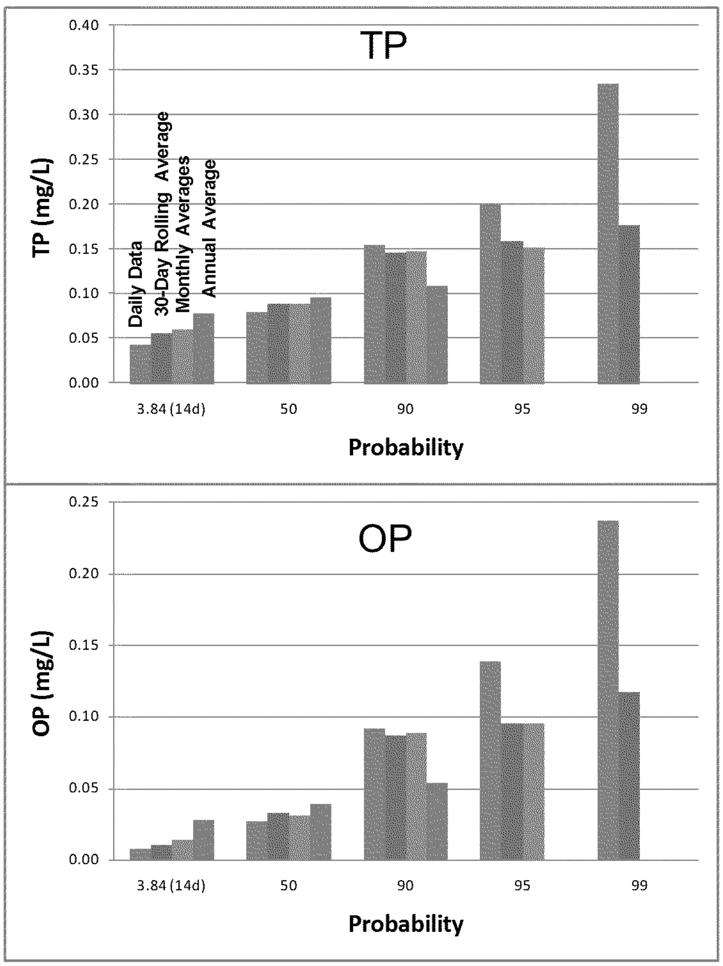

Figure 3-18. Probability Summary for CCWRD.

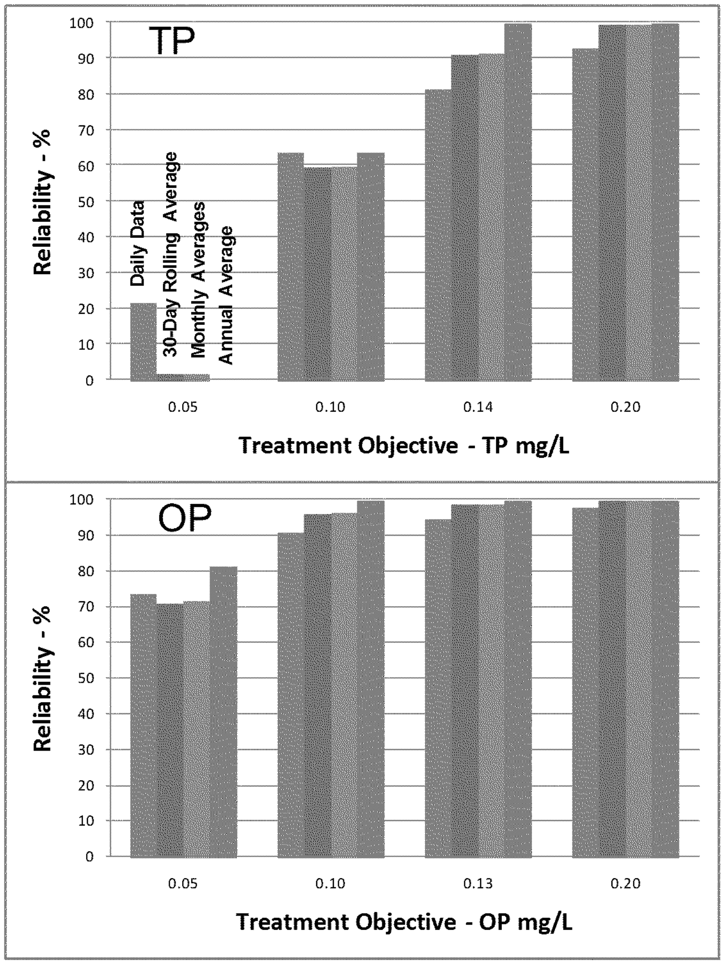

Figure 3-19. Reliability Summary for CCWRD.
Note that the Reliability Calculations Assume that the Data are Log-normally Distributed.

3.5.2 Iowa Hill Water Reclamation Facility, CO

The Iowa Hill WRF in Breckenridge, Colorado was conceived and constructed in the late 1990s to expand the treatment capacity of the Upper Blue Sanitation District. The District serves residents of the upper Blue River watershed including the Town of Breckenridge and Breckenridge Ski Resort. The Iowa Hill WRF utilizes a three stage treatment process including suspended growth activated sludge, biofilm reactor nitrification, and chemical phosphorus removal and can process up to 1.5 MGD. Operations were initiated in March 2000. Figure 3-20 contains the process flow diagram for the plant. Table 3-33 contains the raw influent wastewater design parameters and average influent concentrations.

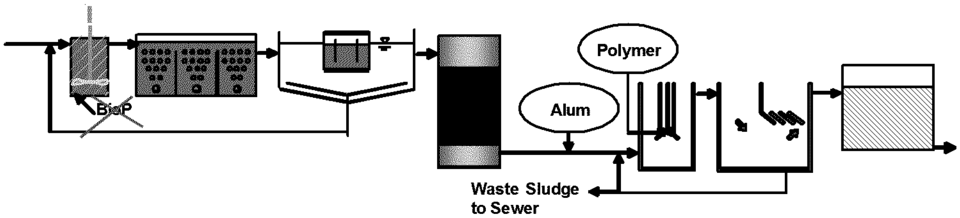

Figure 3-20. Iowa Hill Process Flow Diagram.

Table 3-33. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Iowa Hill WRF from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	1.5	1.1	71
BOD_5 (mg/L)	245	196	57
TSS (mg/L)	234	179	55
Ammonia (mg/L)	50	26.3	38
TP (mg/L)	8	4.0	35
Temperature (°C)	N/A	13.9 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

Raw wastewater is diverted from the main interceptor and is lifted approximately 30 feet to preliminary treatment, comprised of parallel rotary bar screens and a vortex grit separator. Screened influent is mixed with return sludge from the secondary clarifier and split between parallel anaerobic zones. The plant was originally designed for biological phosphorus removal, but as it never worked on startup, the plant is not operated to encourage it. Aeration is by fine bubble diffusers, and clarification is accomplished in rectangular sedimentation basins. Waste sludge is returned to the main interceptor for treatment at the Farmer's Korner WWTF (FKWWTF) another Upper Blue Sanitation District facility. All residuals are processed at FKWWTF by aerobic digestion and centrifugation. Secondary effluent flows by gravity to the flow equalization basin and is pumped through fine screens to tertiary treatment. The nitrification system is comprised of four parallel fixed growth aerated filters with recycle capability. Sodium Hydroxide is added to the nitrified effluent to provide pH control and alkalinity for chemical phosphorus removal. The chemical P unit contains a flash mix chamber for liquid alum addition, a reaction chamber for flocculation with cationic polymer and return chemical sludge, and a sedimentation basin equipped with lamellar tubes. Continuous backwash sand beds provide final filtration prior to disinfection by hypochlorite/bisulfite and ultimate discharge to segment 2a of the Blue River. Table 3-34 provides NPDES permit limits.

Table 3-34. Current NPDES Permit Limits as of October 2008 at the Iowa Hill WRF.

Parameter	30-Day Average	7-Day Average	Daily Max
Flow (MGD)	1.50	N/A	N/A
BOD_5 (mg/L)	30	45	N/A
TSS (mg/L)	30	45	N/A
Total Ammonia-N (mg/L)			
March, April, September	3.5	N/A	N/A
February, August, November, December	4.2	N/A	N/A
January, October	5.5	N/A	N/A
May, July	6.3	N/A	N/A
June	7.6	N/A	N/A
TP (mg/L)	N/A	N/A	0.5
TP (lbs/yr)	225	N/A	N/A

Note:
a. N/A: Data not available or applicable.

3.5.3 F. Wayne Hill, GA

In February 2001 the F. Wayne Hill Water Resources Center became operational and started discharging to the Chattahoochee River. The facility is a combination biological/chemical phosphorus removal facility as seen in Figure 3-21. The biological reactors are comprised of multiple zones with independent DO control. The biological reactors also have recycle pumps to pump mixed liquor from the last aerated zone back to the anoxic zones located at the beginning of the reactor. Chemical addition possibilities in the biological treatment consist of; lime for alkalinity control, metal salts for phosphorus precipitation, and polymers for aided settling. The facility has always operated utilizing biological phosphorus removal as the primary removal mechanism while polishing with metal salts. Biological phosphorus removal in the facility is capable of consistently achieving levels below 0.75mg/L with no chemical addition. Chemical addition just downstream of the biological reactors is used to reach filtered phosphorus levels below 0.1 mg/L. The nominal dosage of alum in this application is between 18 and 22 mg/L. Chemical phosphorus removal occurs in the secondary clarifiers with the sludge being physically removed from the biological process as a part of the biomass in the waste sludge. This sludge is thickened and pumped to an anaerobic digester and ultimately dewatered and transported to a landfill for disposal. Landfill disposal is utilized as it is currently the most cost effective option available in the area. Table 3-35 contains the average influent concentrations. Raw influent design parameters were not provided for the F. Wayne Hill WRF.

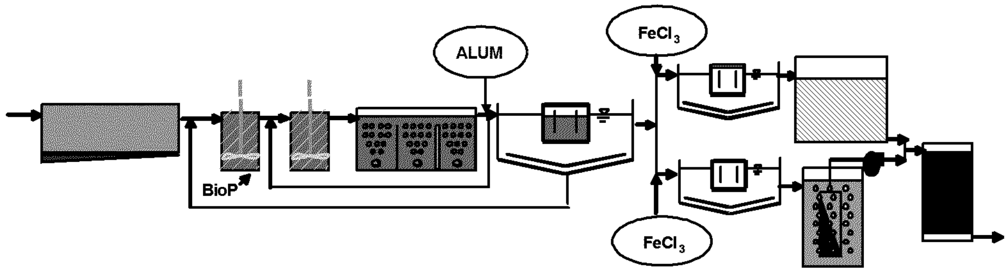

Figure 3-21. F. Wayne Hill Process Flow Diagram.

Table 3-35. Average Raw Influent Concentrations for the F. Wayne Hill WRC from January 2005 Until December 2007.

Parameter	Average Raw Influent
Flow (MGD)	18.4
BOD_5 (mg/L)	281
TSS (mg/L)	969
TKN (mg/L)	46.4
Ammonia (mg/L)	26.6
TP (mg/L)	8.1

Secondary effluent then enters the tertiary treatment process. This process consists of two parallel processes. The original 20 MGD process utilized upflow clarifiers with lime, ferric, or polymers for final phosphorus polishing and deep bed sand filters for filtration. The 40 MGD addition utilizes plate settler clarifiers with ferric and/or polymer addition for final phosphorus polishing and membrane ultrafilters for filtration.

The original 20 MGD facility's original design was based on primarily using high lime dosages to remove phosphorus. This process was extremely effective; however, it was also extremely costly. Excessive costs were seen both in chemical and maintenance costs as well as sludge production and disposal costs. The plant operated for approximately 18 months utilizing lime after which time the switch was made to using ferric chloride. The lime addition required bringing the entire flow stream up to a pH of 10.5 followed by utilization of carbonic acid to return the pH to neutral. The efficient operation of upstream phosphorus removal resulted in approximately 4 tons of lime to be used daily to remove 3-5 lbs. of phosphorus. The use of ferric chloride enabled the facility to reduce the chemical consumption of 4 tons of lime per day to instead being able to operate with a nominal ferric feed rate of 1 to 2 mg/L.

The plate settler/ultrafiltration train is designed to operate as a ferric precipitation system only. The plate settlers and ultrafilters allowed the footprint of the expanded facility to be greatly reduced and produce a higher quality of water. The membrane system is completely automated. The key performance indicator for the membrane system is turbidity. The treated water from the tertiary filtration process consistently produces effluent phosphorus levels below 0.06 mg/L and at times as low as 0.03mg/L. Prior to filtration virtually all of the phosphorus remaining in the flow is associated with very small particulate matter which is removed during filtration. Evaluation of the membranes and deep bed filters demonstrated that although turbidity from the membranes was much lower than that of the deep bed filters, the effluent phosphorus results were virtually the same. The ease of operation of the membranes and the reduced recycle stream combined with the desire to "prove" the membranes has resulted in the facility using the membrane train to treat 80% of the flow coming into the facility. The 60 MGD design is currently treating between 23 and 24 MGD with about 19 MGD being treated by the membrane system.

Following the filtration process the flow continues through a pre-ozonation process which helps to break down larger organic compounds into smaller products making them easier to adsorb in the GAC process that follows. The pre-ozonation process is capable of feeding 1 to 4 mg/L of ozone. The flow then passes through an activated carbon filter which is designed to remove remaining COD in the water. The facilities biological processes perform well enough that the plant no longer operates the pre-ozonation process. The activated carbon is not replaced or reactivated. One half of the activated carbon in the system is virgin carbon that has not been used. The other half is spent and is capable of serving as a biological filter by the addition of the oxygen source from pre-ozonation if needed. Final disinfection follows the activated carbon process. Final disinfection is accomplished with an ozone dosage of 1 to 2 mg/L. The required permit limits for the facility are listed in Table 3-36.

Table 3-36. Original and Current Discharge Permit Limits as of October 2008 for the F. Wayne Hill.

Parameter	Original Permit	Permit for Expanded Plant with Lake Discharge
Flow (MGD)	20	60
COD (mg/L)	25	18
TSS (mg/L)	10	3
Ammonia-N (mg/L)	0.5	0.4
TP (mg/L)	0.13	0.08
Turbidity (NTU)	1.0	0.5
DO (mg/L)	7.0	7.0

3.5.4 Cauley Creek, GA

In May 2002, Georgia's first membrane bioreactor (MBR) plant went on line. The original permit requirements were designed to meet local land application system (LAS) standards. In August of 2003, plant operation strategies changed with the issuance of its new permit allowing for a cold weather discharge and a planned expansion to 5.0 MGD from 2.5 MGD. With this, chemical phosphorus removal began. Several combinations of chemicals were tried and the use of ferric chloride was determined to be the most effective for TP removal and did not impact solids dewatering. The Cauley Creek WRF was issued its existing permit in 2005 allowing for Point Source discharge as well as LAS/REUSE limits with stricter limits on TP, ammonia, and cBOD. Enhanced BNR and MBR is a unique combination because the improved BNR process provides excess phosphorus accumulation in the biomass and the MBR process provides excellent solids-liquid separation which ensures virtually no solids in the treated effluent. Phosphorus can only be removed from wastewater in a solid form – either as a chemical precipitate with chemical P removal or within the biomass with enhanced biological phosphorus removal (BioP). This approach was implemented full scale at the Cauley Creek WRF after extensive wastewater characterization and process modeling (Figure 3-22). The primary objective of the project was to reduce the operating cost of the facility by converting it from a chemical P removal MBR plant to an enhanced BNR MBR plant. Table 3-37 contains the raw influent wastewater design parameters and average influent concentrations.

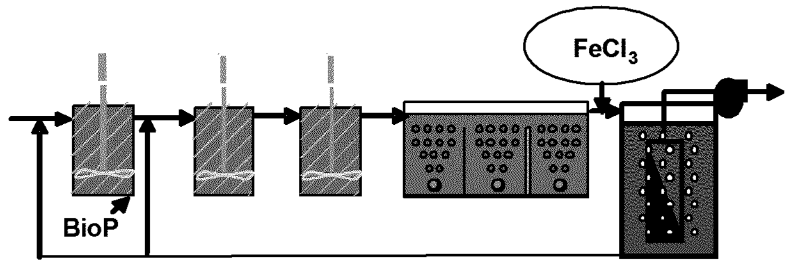

Figure 3-22. Cauley Creek Process Flow Diagram.

Table 3-37. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Cauley Creek WRF from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	5	4.3	86
BOD_5 (mg/L)	N/A	171	N/A
$cBOD_5$ (mg/L)	220	168	65
COD (mg/L)	570	407	61
TSS (mg/L)	225	193	73
TKN (mg/L)	43	34.5	71
Ammonia (mg/L)	32	25.3	69
TP (mg/L)	7.5	6.7	77
Temperature (°C)	N/A	20.3 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

Phase I of the Cauley Creek WRF was designed for an average day capacity of 2.5 MGD with chemical P removal using ZeeWeed® MBR technology. The Phase II expansion was designed for the same capacity as Phase I but with Bio-P removal and supplemental metal coagulant addition for chemical P trimming to consistently achieve the low effluent TP limit of 0.13 mg/L. The plant is designed for complete nitrification to achieve effluent ammonia-N less than 0.5 mg/L. Modeling and simulation using BioWin showed that a modified Johannesburg configuration was the preferred approach for the expansion. The combined average design capacity of Phase I and Phase II is 5.0 MGD and the expansion was commissioned in fall 2004.

The expansion also included a ZeeWeed® membrane sludge thickener to thicken the waste activated sludge (WAS) from around 8,000-10,000 mg/L to as high as 30,000-40,000 mg/L (3-4%) before sending it to the aerobic sludge digester. This provides the added benefit of removing water from the WAS that is similar in quality to the plant effluent. The aerobically digested sludge is dewatered using centrifuge to between 19-22 weight percent and the centrate is returned to the deoxygenation/denitrification zone.

As detailed in the "Guidelines for Water Reclamation and Urban Water Reuse" issued by the Georgia Environmental Protection Division (EPD), wastewater is required to undergo treatment that includes biological oxidation, clarification, coagulation, filtration, and disinfection prior to urban reuse. Reuse water is required to have a BOD_5 equal to or less than 5 mg/L, TSS equal to or less than 5 mg/L, a fecal coliform count equal to or less than 23 colonies per 100 mL, pH between 6 and 9 standard units, and turbidity equal to or less than 3 NTUs.

Based on the need to meet the above criteria for urban water reuse and EPD's cold weather surface discharge requirements, the design effluent quality is as summarized in Table 3-38 below.

Table 3-38. Current NPDES Discharge Permit Limits as of October 2008 for the Cauley Creek WRF.

Parameter	Reuse	Monthly Average
cBOD (mg/L)	<5.0	2.9
TSS (mg/L)	<5.0	5.0
Turbidity (NTU)	<3.0	3.0
TP (mg/L)	N/A	0.13
Ammonia-N (mg/L)	≤1.0	0.5

Note:
a. N/A: Data not available or applicable.

3.5.5 Pinery, CO

Overall nutrient removal has been the key goal for the Pinery Water & Wastewater District since the 1980s. District Management and the Board of Directors recognized the importance of nutrient removal from wastewater prior to discharge to the sensitive Cherry Creek watershed. Cherry Creek Reservoir is located on the southern edge of the Denver Metro area, and is fed from Cherry Creek. Water quality concerns in the reservoir started in the early 1980s and promoted the formation of Cherry Creek Water Authority that monitors water quality in the stream and reservoir. Possible pollution sources were identified both point and nonpoint, phosphorus was identified as the primary nutrient causing algal production in the reservoir.

The Pinery Water & Wastewater District started construction of a 1 MGD, 5-stage Bardenpho with tertiary treatment using a contact clarifier/filter process (Trident Micro Floc Adsorption Clarifier/Filter) in 1989. The project was completed and put online in April of 1991. To comply with current and future anticipated phosphorus requirements, three additional construction projects have been completed since that time. Phases one and two were completed in 2005, adding two adsorption clarifier/filters, increasing equalization capacity, and adding a facility wide SCADA system to aide in compliance with new phosphorus limitations and other permit changes. Previously no automation existed at this facility. Upgrades to the existing Bardenpho process included a new aerator with VFD control and two new recycle pumps with VFD control, two additional aerated sludge holding tanks and a new pretreatment building. Wasted solids are dewatered with a belt filter press and then composted. This project increased the tertiary capacity to 2 MGD. Phase three construction, completed in 2008 added an additional 5-stage Bardenpho secondary process to the facility, increasing the secondary capacity to 2 MGD as seen below in Figure 3-23. Table 3-39 contains the raw influent wastewater design parameters and average influent concentrations.

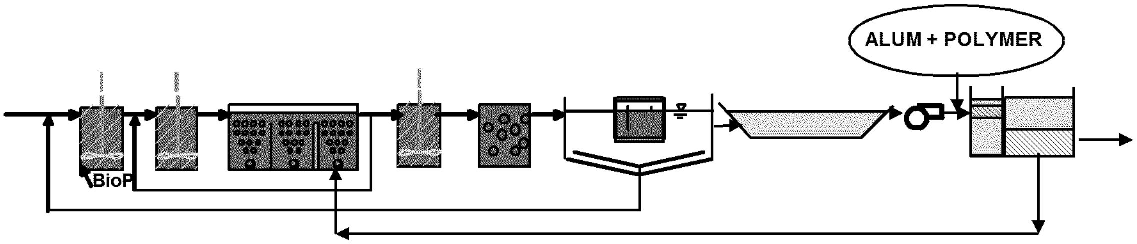

Figure 3-23. Pinery Process Flow Diagram.

Table 3-39. Design and Average Raw Influent Concentrations and Percent of Design Load for the Pinery WWTP from January 2006 Until December 2008.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	2	0.6	32
BOD_5 (mg/L)	270	229	27
COD (mg/L)	N/A	616	N/A
TSS (mg/L)	290	265	29
Ammonia (mg/L)	50	35.1	22
TP (mg/L)	8	8.5	34
Temperature (°C)	N/A	16.2	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. N/A: Data not available or applicable.

This facility has two discharge points but dealing with very different parameters. Table 3-40 shows the discharge requirements for the alluvial discharge using rapid infiltration (RI) basins. This discharge is influenced primarily by drinking water standards. Table 3-40 also contains the requirements for discharging to Cherry Creek. This creek supplies water to a recreational area located on the south edge of the Denver Metro area.

Table 3-40. Current NPDES Permit Limits as of October 2009 for the Pinery WWTP.

Parameter	30-Day Average	Maximum
All Discharge Points		
Flow (MGD)	2.0	N/A
BOD (mg/L)	30	45 (7-Day Average)
TP (mg/L)	0.05	0.1 (Daily)
TP (lbs/day)	N/A	304 (Annual)
Discharge to RI Basins		
Nitrate-N (mg/L)	N/A	10 (Daily)
TDS (mg/L)	825	N/A
Discharge to Cheery Creek		
Nitrate-N (mg/L)	N/A	11 (Daily)
TSS (mg/L)	30	45 (7-Day Average)

Note:
a. N/A: Data not available or applicable.

For years, chemical addition and filtration provided phosphorus removal to low levels with minimal regulatory concerns. Staff's primary focus has been chemical cost containment. However, when the district's new permit added restrictions on pH, sulfate, and TDS, staff realized filtration could still polish the final effluent but consistent and significant secondary phosphorus removal was critical for successful operations and compliance with current permit requirements.

3.5.6 Alexandria Sanitation Authority, VA

The Alexandria Sanitation Authority (ASA) Advanced Wastewater Treatment Facility is a 54 MGD wastewater treatment facility located in Alexandria, Virginia. The facility currently serves about 350,000 people in the City of Alexandria and adjacent portions of Fairfax County. The plant discharge flows into the Potomac River and the Chesapeake Bay.

The ASA facility was upgraded in 2002 in order to meet annual average TN concentration goal of 8 mg/L and while continuing to meet a monthly average TP concentration limit of 0.18 mg/L. The upgrade included replacement of the plant's rotating biological contactors with a suspended growth activated sludge system and an upgraded tertiary treatment process to remove TSS and TP using inclined plate settling tanks and deep bed sand filters. WAS and tertiary sludge are thickened with centrifuges and blended with gravity thickened primary sludge before anaerobic digestion. Digested sludge is dewatered with centrifuges and disposed of offsite. Figure 3-24 illustrates the overall liquids treatment process at ASA. Table 3-41 contains the raw influent wastewater design parameters and average influent concentrations.

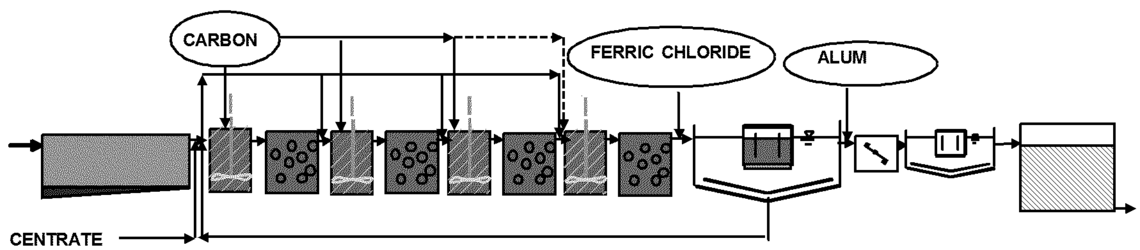

Figure 3-24. ASA Process Flow Diagram.

Table 3-41. Design and Average Raw Influent Concentrations and Percent of Design Loads for the ASA AWTF from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	54	37.4 [b]	69
BOD_5 (mg/L)	151	179	82
$cBOD_5$ (mg/L)	N/A	179	N/A
TSS (mg/L)	145	259	124
TKN (mg/L)	32	34.7	75
Ammonia (mg/L)	20.4	20.6	70
TP (mg/L)	3.8	6.0	111
Temperature (°C)	N/A	20.6 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent value.
c. N/A: Data not available or applicable.

In 2004, Virginia's Secretary of Natural Resources began the process of enacting new regulations in order to reduce nutrient levels in the Chesapeake Bay to meet the goals of the Chesapeake 2000 Agreement. The regulations include lower nutrient limits on wastewater treatment plant discharges that would require exceptionally low treatment objectives for nitrogen and phosphorus removal. Starting in 2011, the ASA facility will have to meet a waste load allocation associated with an annual average TN concentration limit of 3 mg/L at 54 MGD and continue to meet a monthly average TP concentration limit of 0.18 mg/L. These limits are summarized below in Table 3-42.

Table 3-42. Current NPDES Permit Limits as of October 2009 at the ASA AWTF.

Parameter	Annual Average	Monthly	Weekly
TP (mg/L)	N/A	0.18	0.27
Ammonia-N (mg/L)			
Apr – Oct	N/A	1.0	4.4
Nov – Jan	N/A	8.4	10.4
Feb - Mar	N/A	7.4	9.1
TN (mg/L)	6	N/A	N/A
Future TN (mg/L)	3	N/A	N/A

Note:
a. N/A: Data not available or applicable.

In response to the new regulations, ASA initiated a nitrogen removal optimization program to increase the performance of the existing system. Modifications were made to the operation of the existing biological reactor basins and the methanol addition system to improve nitrogen removal.

3.5.7 Rock Creek, OR

The Rock Creek AWTF is located at 3235 SW River Road, Hillsboro Oregon. It serves over 200,000 customers located in Washington County, Oregon. Rock Creek AWTF is currently rated at 148,000 m^3/d (39 MGD) dry weather average flow. Ammonia and phosphorus removal is required only during the dry season (May 1-October 31). The plant uses a combination of chemically enhanced primary treatment, secondary activated sludge, tertiary flocculation, coagulation, clarification followed by granular media filtration (see Figure 3-25) to achieve the phosphorus and ammonia limits (Table 3-44). The plant employs two types of tertiary clarifiers, conventional units and Claricone™ upflow solids contact units. Table 3-43 contains the raw influent wastewater design parameters. Raw influent data was not provided for the Rock Creek AWTF.

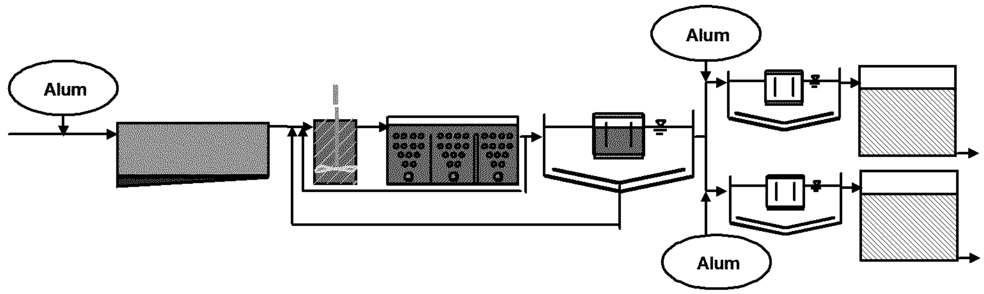

Figure 3-25. Rock Creek Process Flow Diagram.

Table 3-43. Raw Influent Design Concentrations for the Rock Creek AWTF from January 2005 Until December 2007.

Parameter	Raw Influent Design
Flow (MGD)	40
$cBOD_5$ (mg/L)	152
TSS (mg/L)	175
Ammonia (mg/L)	14
TP (mg/L)	5.5

Flow is comprised of 90% domestic and 10% industrial and commercial. One or more of five available pumps transfer raw sewage to three mechanical fine screens. Total pumping capacity is 175 MGD. The flow pumped to the mechanical fine screens is measured using magnetic flow meters located in the dual force mains. The three fine screens have a total capacity of 200 MGD.

The screened sewage then flows to one or more of three primary sedimentation tanks. Three circular tanks, each with a volume of 1.62 MG, are used for flows up to 150 MGD. For flows greater than 150 MGD, two additional surge tanks, with a volume of 0.560 MG each, are used. The primary effluent flow can be sent to either of two secondary treatment systems designed to perform biological nutrient removal.

The west-side system, rated at 18 MGD dry weather flow, consists of two diffused air aeration basins followed by six secondary clarifiers. The aeration basins have a volume of 2.17 MG each and the secondary clarifiers have a volume of 0.968 MG each. During the phosphorus removal season, west secondary effluent is directed to two converted secondary clarifiers which serve as chemical clarifiers in this flow mode. Effluent from these chemical clarifiers then flows to the four mixed media gravity filters on the west side of the plant.

The east-side system, rated at 24 MGD dry weather flow, consists of three diffused air aeration basins followed by three secondary clarifiers. The three aeration basins have a volume of 1.70 MG each and the secondary clarifiers have a volume of 2.07 MG each. Also during the phosphorus removal season, east secondary effluent can be directed to four Claricone™ upflow solids contact chemical clarifiers, which have a combined flow capacity of 20 MGD. When these units are in use, flows in excess of 20 MGD are directed to two direct filtration channels prior to filtration. Tertiary effluent from the eastside system flows through ten mono-media deep bed anthracite gravity filters.

Filtered effluent flows into three chlorine contact basins; the east basin with a volume of 0.697 MG and two west basins with a volume of 0.317 MG each. Filtered effluent is de-chlorinated and discharged to the Tualatin River via two outfall lines, one 60-inch and one 96-inch. Effluent flow may alternatively be directed to reuse pumps depending on irrigation demand.

The original 1978, Rock Creek AWTF provided dry season phosphorus removal of 75% (A monthly average limit of 2.5 mg/L). Effective in 1993, the implementation of a TMDL led to a low level TP limit of 0.10 mg/L. The limit was actually mass based in a matrix format. The monthly median limit would range from 0.07 mg/L to 0.15 mg/L, depending on the matrix conditions. This mass based monthly median phosphorus limit was in effect from 1993 through 2003. The current permit, issued in February 2004, has a TP concentration based limit of 0.10 mg/L computed as a monthly median. Table 3-44 lists the current Rock Creek AWTF effluent permit requirements.

Table 3-44. Current NPDES Permit Limits as of October 2008 for Rock Creek AWTF.

Parameter	Monthly Average	Weekly Max	Daily
Wet Season			
$cBOD_5$ (mg/L)	20	30	N/A
$cBOD_5$ (kg/day)	3182	4545	6364
TSS (mg/L)	20	30	N/A
TSS (kg/day)	3182	4545	6364
Dry Season			
$cBOD_5$ (mg/L)	8	11	N/A
$cBOD_5$ (kg/day)	591	864	1136
TSS (mg/L)	8	11	N/A
TSS (kg/day)	591	864	1136
Ammonia-N (kg/day)			
May	N/A	830	N/A
June	N/A	638	N/A
July	N/A	107	N/A
August	N/A	99	N/A
September	N/A	89	N/A
October	N/A	97	N/A
TP (mg/L)	0.10 [b]	N/A	N/A

Note:
a. N/A: Data not available or applicable.
b. Monthly median.

Primary solids are settled and thickened to 1% solids in the primary sedimentation tanks. The resultant sludge is raked into hoppers from where it is pumped to the vortex grit separator. The degritted primary sludge is then pumped to the thickening feed tank (TFT). The TFT has a volume of 0.66 MG. WAS is drawn from the RAS with centrifugal pumps and discharged to the TFT where it is mixed with the primary solids. The mixed TFT solids are then pumped to a gravity belt thickener and thickened to between 5-7% total solids concentration. The thickened sludge is pumped to the anaerobic digestion process. The anaerobic digestion process consists of a total of six digester tanks. Solids stay in the active anaerobic digesters an average of 22 days. The operating temperature of the anaerobic digesters is 97°F. Volatile solids reduction averages between 50 and 60%. The digested biosolids are pumped to the dewatering process. The dewatering process consists of one centrifuge and four twin belt presses. Digested biosolids are conditioned with polymer and dewatered to between 14-16% solids on the twin belt presses or to 22-25% solids in the centrifuge. The digested, dewatered biosolids are conveyed to two storage silos from where they are loaded into trucks for land application. The Rock Creek Facility has an annual biosolids production, after anaerobic digestion and dewatering, of approximately 7,000 dry tons per year.

3.5.8 Blue Plains, DC

The Chesapeake Bay and the Potomac River are environmentally sensitive receiving waterbodies for several large wastewater treatment plants. Consequently, effluent phosphorus limits are extremely low for the Potomac River and the nitrogen removal requirements are becoming increasingly stringent. Thus, the wastewater treatment plants that discharge into the middle and lower Potomac have some of the most extensive nutrient removal capabilities in the entire world. The District of Columbia Advanced Wastewater Treatment Plant at Blue Plains is the largest advanced nutrient removal plant in North America, with a rated capacity of 370 MGD. The phosphorus limits for the plant include a 0.18 mg/L annual rolling average and a 0.35 mg/L weekly average. Table 3-45 shows the permit limits for the plant. The Blue Plains full plant liquid-side flow diagram is shown in Figure 3-26. Table 3-46 contains the raw influent wastewater design parameters and average influent concentrations.

Table 3-45. Current NPDES Permit Limits as of October 2008 at the Blue Plains AWTP.

Parameter	Annual Average	Monthly Average	Weekly Max
$cBOD_5$ (mg/L)	N/A	5.0	7.5
TSS (mg/L)	N/A	7.0	10.5
Ammonia-N (mg/L) (Summer)	N/A	4.2	6.1
Ammonia-N (mg/L) (Winter)	N/A	11.1	14.8
TP (mg/L)	0.18 (Rolling)	N/A	0.35
TN (mg/L) (Current goal)	7.5	N/A	N/A
TN (mg/L) (Future limit)	4.2	N/A	N/A

Note:
a. N/A: Data not available or applicable.

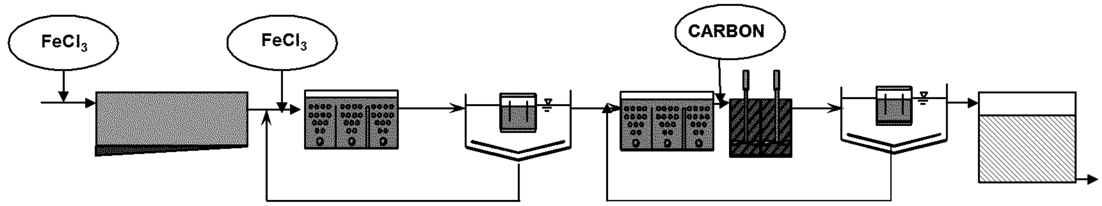

Figure 3-26. Blue Plains Process Flow Diagram.

Table 3-46. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Blue Plains AWTP from January 2005 until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	370	312.6	84
BOD_5 (mg/L)	132	N/A	N/A
TSS (mg/L)	136	214	133
TKN (mg/L)	23	28.9	106
Ammonia (mg/L)	N/A	16.6	N/A
TP (mg/L)	3	4.2	118
Temperature (°C)	N/A	19.1 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent temperature.
c. N/A: Data not available or applicable.

The phosphorus removal process is based on iron dosing to the primary and the secondary processes. The combined chemical dosage for phosphorus removal at the plant is between 7-8 mg/L as Fe with an influent TP of 4.9 mg/L and an approximate influent OP/TP ratio of between 0.5 and 0.6. There was a significant increase in influent phosphorus in 2004 when the water utilities in the Blue Plains service area began adding phosphate to the water supply for corrosion control. The primaries operate as Chemically Enhanced Primary Treatment (CEPT) to maximize the solids and organic removal with a ferric chloride dose of about 5 mg/L as Fe. A smaller fraction of the iron dose of about 2-3 mg/L as Fe is added to the high rate secondary treatment step, to achieve simultaneous precipitation. The nitrification/denitrification stage following the secondary stage does not receive an iron dose, but contains large amounts of precipitated phosphorus carried over from the secondary clarifiers in the suspended solids.

Primary sludge is gravity thickened and blended with WAS that has been thickened by dissolved air flotation. The solids are dewatered using centrifuges and belt filter presses and then stabilized with lime to produce biosolids for land application.

3.5.9 Kelowna, BC

The City of Kelowna is located in the interior of the Province of British Columbia on the eastern shore of Lake Okanagan and has a current population approaching 100,000, of which about 85,000 are serviced by a sewer system. A peak population of up to 120,000 occurs in the summer months due to the popularity of the Kelowna area as a tourist destination.

Lake Okanagan is a freshwater lake with a hydraulic retention time estimated to be in the order of 70 years. This turnover rate has caused the B.C. Ministry of Environment to consider the lake to be nutrient-sensitive and therefore communities discharging treated effluent to the lake have been subject to stringent nitrogen and phosphorus limits.

Kelowna is the largest urban community on the lake and has provided wastewater treatment for its inhabitants since 1910. In the early 1980s, Kelowna constructed one of the first biological nutrient removal plants in North America employing a 5-stage Bardenpho configuration to replace an existing conventional plant to meet the needs of a growing population and to preserve the water quality in Lake Okanagan. The nominal design capacity of the plant is 40 MLD (10.6 MGD).

The treated effluent quality limits specified in the Operational Certificate for the Kelowna Wastewater Treatment Facility (WWTF) are listed in Table 3-47. These limits are among the most stringent applied to a community of this size in Canada.

Table 3-47. Current Treated Effluent Quality Limits as of October 2009 for the Kelowna WWTF.

Contaminant	Limit	Basis
BOD_5 (mg/L)	10	Monthly Average
TSS (mg/L)	10	Monthly Average
TP (mg/L)	2.0	Not to Exceed
TP (mg/L)	1.5	99^{th} Percentile
TP (mg/L)	1.0	90^{th} Percentile
TP (mg/L)	0.25	Annual Average
TP (mg/L)	0.10	"Level to strive for"
TN (mg/L)	6.0	Monthly Average

A schematic block diagram of the Kelowna WWTF process is sketched in Figure 3-27. The biological nutrient removal system is currently configured as a modified 3-stage Bardenpho (also known as the West Bank process) design consisting of four trains in parallel – two larger trains each with 14 cells and two smaller trains each with seven cells. Each train consists of three zones: anaerobic, anoxic and aerobic. Primary sludge fermenter effluent, rich in volatile fatty acids (VFAs) that aid in biological phosphorus removal, is directed to the anaerobic zone of each train. Internal nitrified mixed liquor recycle pumps return mixed liquor from the end of each aerobic zone to the beginning of the anoxic zone at a rate varying between 4 to 6 times the primary effluent flow rate. Secondary clarifier effluent is directed to a dual media granular filtration system. The filtered effluent is subject to ultraviolet disinfection prior to discharge to Lake Okanagan via a 1.2 km (~¾ mile) outfall and diffuser at a depth of 65 m (~215 ft). Table 3-48 contains the raw influent wastewater design parameters and average influent concentrations.

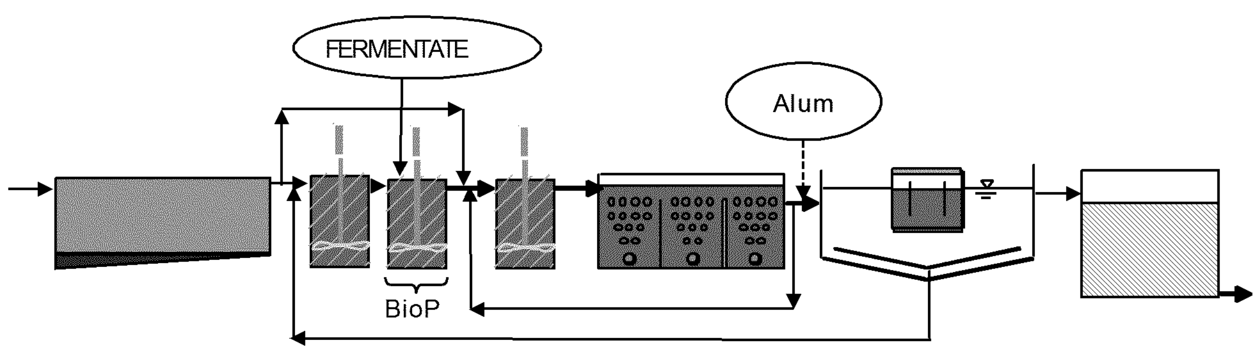

Figure 3-27. Kelowna Process Flow Diagram.

Table 3-48. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Kelowna WWTF from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	10.6	8.8	84
BOD_5 (mg/L)	196	296	126
COD (mg/L)	N/A	733	N/A
TSS (mg/L)	196	475	202
TKN (mg/L)	42	34.9	69
Ammonia (mg/L)	N/A	18.0	N/A
TP (mg/L)	7.4	6.7	75
Temperature (°C)	N/A	17.2 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average bioreactor temperature.
c. N/A: Data not available or applicable.

The solids processing train consists of a primary sludge fermentation system, dissolved air flotation for waste activated sludge, centrifuge dewatering of fermented primary sludge and thickened waste activated sludge to approximately 20% dry solids content. The sludge cake is trucked to an offsite composting facility where it is combined with wood waste and composted to a high quality soil conditioner called “Ogogrow,” named after the legendary “Ogopogo” aquatic monster alleged to inhabit Lake Okanagan and claimed to be spotted by observers from time to time.

3.5.10 Kalispell, MT

A BNR plant went online in Kalispell, Montana, in late 1992 for the principle reason of reducing the amount of phosphorus discharged into pristine Flathead Lake. In addition, potential ammonia toxicity impacts on the receiving stream due to its very low summer dilution flows required the plant to seasonally nitrify to reliably achieve low ammonia nitrogen concentrations. The plant utilizes the modified University of Cape Town (m-UCT) system (see Figure 3-28) and is designed to process 3.1 MGD. Table 3-49 contains the raw influent wastewater design parameters and average influent concentrations.

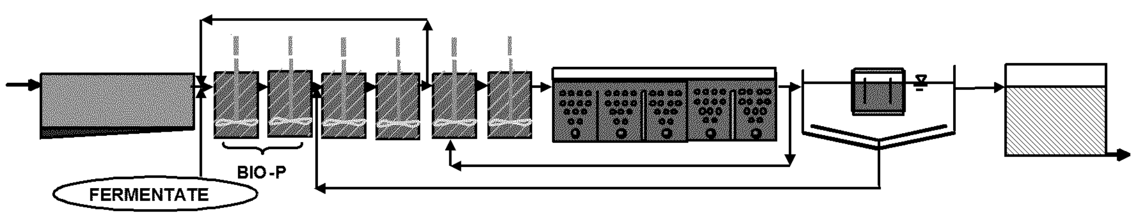

Figure 3-28. Kalispell Process Flow Diagram.

Table 3-49. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Kalispell WWTP from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	3.1	2.9	92
BOD_5 (mg/L)	215	231	99
TSS (mg/L)	260	204	72
TKN (mg/L)	25	36.7	136
Ammonia (mg/L)	N/A	26.3	N/A
TP (mg/L)	6.5	4.5	64
Temperature (°C)	N/A	14.9	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. N/A: Data not available or applicable.

Wastewater treatment begins with flow entering the plant via a 36-inch diameter pipe from the city sanitary sewer collection system. This influent flows through the headworks and is pumped to two rectangular primary clarifiers by five low-head centrifugal lift pumps. Primary clarifier effluent then flows into the bioreactor which consists of 11 tanks in series. During daily periods of peak flow, a pre-determined amount of primary effluent is directed to an equalization basin. Flow from the equalization basin is then returned to the primary clarifiers during periods of low influent flow. The bioreactor uses the m-UCT process, consisting of four zones (anaerobic, first anoxic, second anoxic, and aerobic) to maximize nutrient removal. The bioreactor is designed to be flexible, containing cells with more than one mode of operation, called “swing zone” cells. These cells are used to alter the zone size and/or allow different seasonal modes of operation to maximize nutrient removal. Bioreactor effluent then flows to two circular secondary clarifiers and then through an effluent deep bed sand filter with an up-flow, continuous backwash design. The filtered effluent passes through an ultraviolet disinfection system and is re-aerated before discharging to the receiving stream. Discharge permit limits are summarized in Table 3-50 below.

Table 3-50. Current NPDES Permit Limits as of October 2009 at the Kalispell WWTP.

Parameter	30-Day Average	7-Day Average
Flow (MGD)	3.1	N/A
BOD_5 (mg/L)	10	15
TSS (mg/L)	10	15
TP (mg/L)	1.0	N/A

Note:
a. N/A: Data not available or applicable.

The solids process train starts with removing primary sludge from the primary clarifiers with two sludge pumps to a complete mix fermenter. Fermented waste sludge flows to a gravity thickener; two pumps return the fermenter supernatant to the bioreactor. Sludge from the gravity thickener is pumped to the primary digester which then over flows to two secondary digesters. Digested primary sludge is dewatered with two belt filter presses. Secondary sludge is pumped as return activated sludge to the bioreactor. RAS is also pumped by two pumps to two dissolved air flotation thickeners for wasting. DAF supernatant is wasted back to the bioreactor and the thickened sludge from the DAF is pumped via two DAF float pumps to two belt filter presses where it is mixed with digested primary sludge just before the presses. The BFP cake is trucked to an offsite private composting operation.

3.6 Nitrification Reliability Plants

3.6.1 Kalkaska, MI

Prior to 2003, the Village of Kalkaska treated their wastewater in a series of lagoons. When faced with rapid residential, commercial, and industrial expansion that outgrew the existing treatment, the Village turned to engineering firm Gosling Czubak Engineering Sciences for a solution. The solution was the construction of a 0.6 MGD extended aeration facility to treat existing flow and organic loading that would meet increasing regulatory requirements and be capable of expanding to meet future needs (Figure 3-29). In need of certified operating personnel, the Village contracted with Severn Trent Services to start up, operate and maintain the plant. The $5.5 million Clean Water Plant started operation in September 2003. Originally scheduled for completion on July 1, 2003, the plant was dedicated and named the Kalkaska Clean Water Plant in November 2003. The facility currently serves 2,230 residents. Table 3-51 contains the raw influent wastewater design parameters and average influent concentrations.

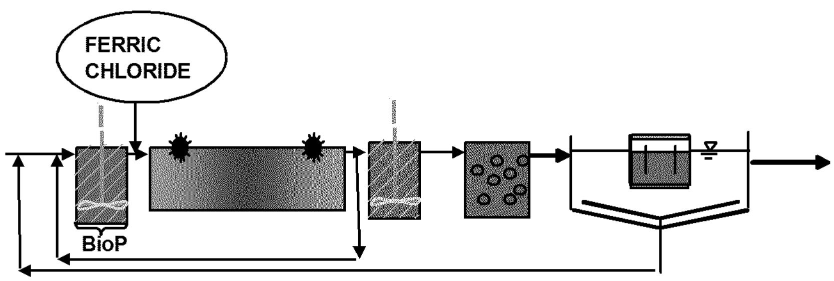

Figure 3-29. Kalkaska Process Flow Diagram.

Table 3-51. Design and Average Raw Influent Concentrations and Percent of Design Load for the Kalkaska CWP from January 2006 Until December 2008.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	0.6	0.28 [d]	47
$cBOD_5$ (mg/L)	250 [b]	301	N/A
TSS (mg/L)	250	244	45
TKN (mg/L)	40 [c]	N/A	N/A
Ammonia (mg/L)	N/A	27.3	N/A
TP (mg/L)	N/A	7.8	N/A
Temperature (°C)	N/A	13.2 [d]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Raw influent design value as BOD_5.
c. Raw influent design value as TIN.
d. Average final effluent value.
e. N/A: Data not available or applicable.

All wastewater, domestic and industrial, from the village is collected and routed through three lift stations and pumped through a force main to the head works of the plant where it first passes through a rotating mechanical fine screen and then through a grit chamber that uses an airlift pump to deposit all the grit into a dumpster. The influent then flows into a chamber where it is mixed with return activated sludge. At this point of the process the flow can be diverted into one or both first anoxic basins that are built parallel to each other and mix the influent and return activated sludge into a mixed liquor using a submersible mixer. Each first anoxic basin is directly attached its respective carousel oxidation ditch which uses a large partially submerged impellor to both aerate the mixed liquor and maintain a flow in a constant circular direction. The mixed liquor then either flows over a weir that sends it to the ditch's respective second anoxic basin or a portion of it returns to the first anoxic basin through an internal recirculation gate that regulates the internal recycle rate to the first anoxic basin. Once in the second anoxic basin, the mixed liquor is mixed again with a submersible mixer and flows over a weir to the re-aeration chamber. Using fine air diffusion, the reaeration chamber strips any remaining nitrogen gas from the mixed liquor. Ferric chloride is fed into the mixed liquor at this point to remove phosphorus. After flowing over another weir, the effluent is separated from the activated sludge in one of two parallel circular clarifiers. Effluent then flows out to two of four rapid infiltration basins where it seeps into the underlying groundwater. The discharge limits are summarized below in Table 3-52.

Table 3-52. Groundwater Discharge NPDES Permit Limits from September 2003 to September 2008 at the Kalkaska CWP.

Parameter	Limitation	Frequency
Flow (GPD)	600,000	Daily
Flow (MGY)	219	Annual
TIN (mg/L)	5	Weekly
TP (mg/L)	2	Monthly

Return activated sludge is pumped from the bottom of the clarifier to the chamber before the first anoxic basins and a portion is diverted to a waste tank daily. The waste activated sludge is then run through a drum thickener where is it dewatered to 5% solids and pumped to the aerobic digester. Once finished digesting, the sludge is sent to storage tanks with a combined capacity of half a million gallons. The biosolids are land applied once per year by a licensed biosolids applications contractor.

3.6.1.1 Example Nitrification Reliability Data Set – Kalkaska CWP

One operational problem reported is the effect of sludge storage supernatant on the biological nitrogen performance of the Kalkaska Clean Water Plant. As described by the plant manager, the facility had one exceedance (0.65% of the time) on their total inorganic nitrogen limit during the period analyzed due the high ammonia loads coming from the supernatant. Higher effluent TIN concentrations often occur in the spring, when the sludge storage tanks need to be decanted and the influent wastewater temperatures were still cold enough to cause slow biological activity. Based on the data, a clear indication of high effluent TIN values caused by supernatant management during the spring period was observed.

However, it should be noted this problem was resolved by diverting the supernatant to the aerobic digesters for partial nitrification before reintroducing it back to the liquid process.

Figure 3-30 through Figure 3-33 and Table 3-53 through Table 3-55 provide an example of the statistical summary compiled for the Kalkaska Clean Water Plant (CWP) treatment facility which has a current weekly TIN permit limit of 5.0 mg/L. Several observations are provided for these data:

- Figure 3-30: Comparing the TIN 30-day rolling average to the 5.0 mg/L permit limit, it is obvious that the treatment objective is easily being met. This figure also shows that the TIN is predominately comprised of NO_X-N.
- Figure 3-31: Probability plots suggest relatively good conformance with the log-normal distribution for TIN and NO_X-N, with some deviation at high concentrations. As expected with averaging of the data set and attenuation of the upset events with longer averaging periods, better log-normal conformance is observed in Figure 3-31B, Figure 3-31C, and Figure 3-31D.
- Table 3-53 through Table 3-55 and Figure 3-32: If only one year of data was examined, the maximum value (Table 3-53 through Table 3-55) for the 30-day rolling average and monthly average data should be roughly equal to the 92nd percentile, which approximates the maximum month condition. Considering the database had 36 months and the range shown in Figure 3-32 for the daily 90-95% probabilities, it appears that this is the case.
- Figure 3-33: While weekly statistical analyses were completed, the Kalkaska CWP is quite reliable at the weekly TIN permit limit of 5.0 mg/L. The NH_3-N plot indicates that Kalkaska can reliably achieve low effluent ammonia concentrations, particularly because it can be evaluated on a weekly basis.

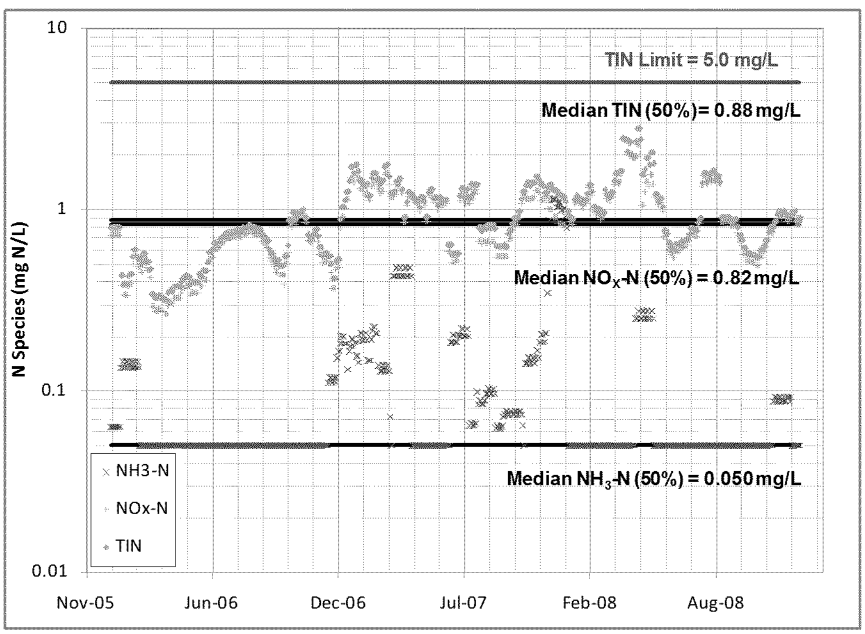

Figure 3-30. 30-Day Rolling Average Time Series Plot for Kalkaska Clean Water Plant.

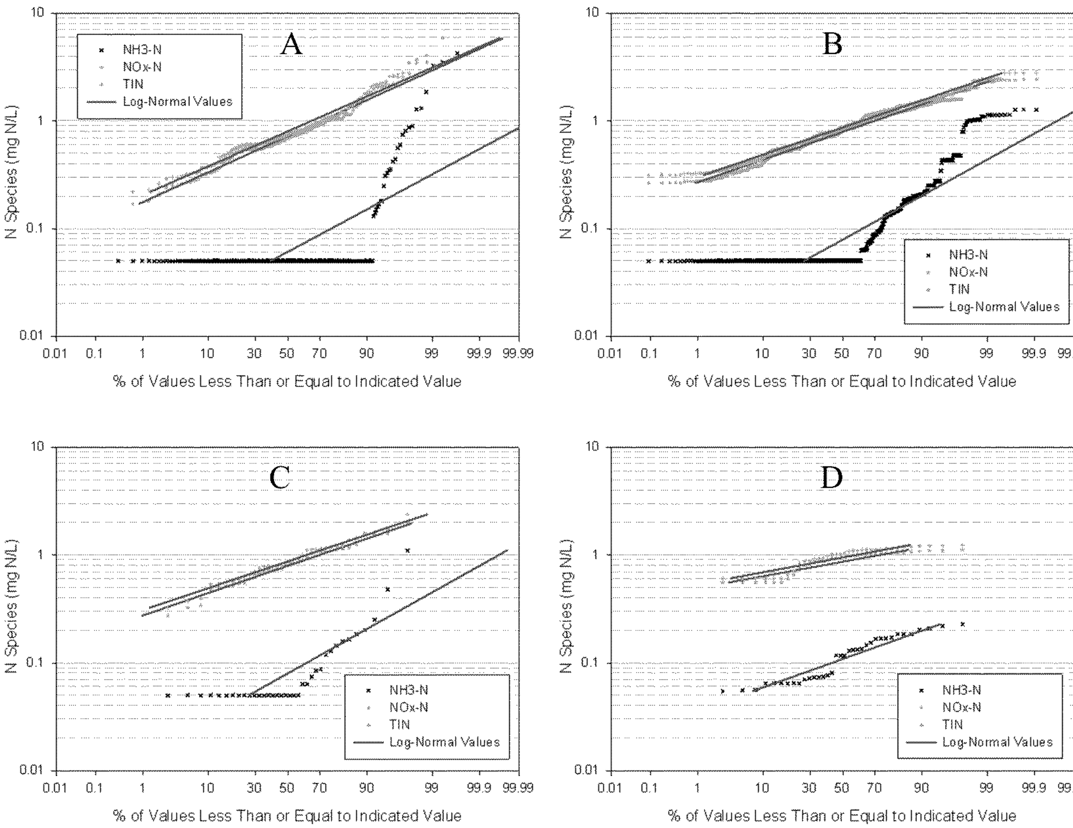

Figure 3-31. Probability Plots for Kalkaska Clean Water Plant –
(A) Daily Data; (B) 30-day Rolling Average; (C) Monthly Averages; (D) Annual Average.

Table 3-53. Summary Statistics of Final Effluent NH_3-N for Kalkaska Clean Water Plant.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	309	1096	36	36
Mean	0.12	0.12	0.12	0.12
Geometric Mean	0.061	0.079	0.080	0.11
Std. Dev.	0.40	0.18	0.19	0.055
CoV	3.25	1.50	1.56	0.46
Skew	7.86	4.33	4.49	0.39
Minimum	0.050	0.050	0.050	0.050
Maximum	4.24	1.27	1.11	0.23

Table 3-54. Summary Statistics of Final Effluent NO_X-N for Kalkaska Clean Water Plant.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	155	1096	36	36
Mean	0.89	0.88	0.88	0.89
Geometric Mean	0.72	0.79	0.80	0.87
Std. Dev.	0.71	0.40	0.39	0.19
CoV	0.80	0.46	0.44	0.21
Skew	3.39	1.01	0.84	-0.83
Minimum	0.17	0.27	0.28	0.56
Maximum	5.85	2.43	1.97	1.12

Table 3-55. Summary Statistics of Final Effluent TIN for Kalkaska Clean Water Plant.

	Daily Data	30-Day Rolling Average	Monthly Averages	Annual Average
n	155	1096	36	36
Mean	0.97	0.96	0.96	0.98
Geometric Mean	0.80	0.87	0.88	0.95
Std. Dev.	0.76	0.44	0.43	0.22
CoV	0.79	0.46	0.45	0.22
Skew	3.11	1.06	1.14	-0.69
Minimum	0.22	0.32	0.33	0.61
Maximum	5.90	2.80	2.38	1.24

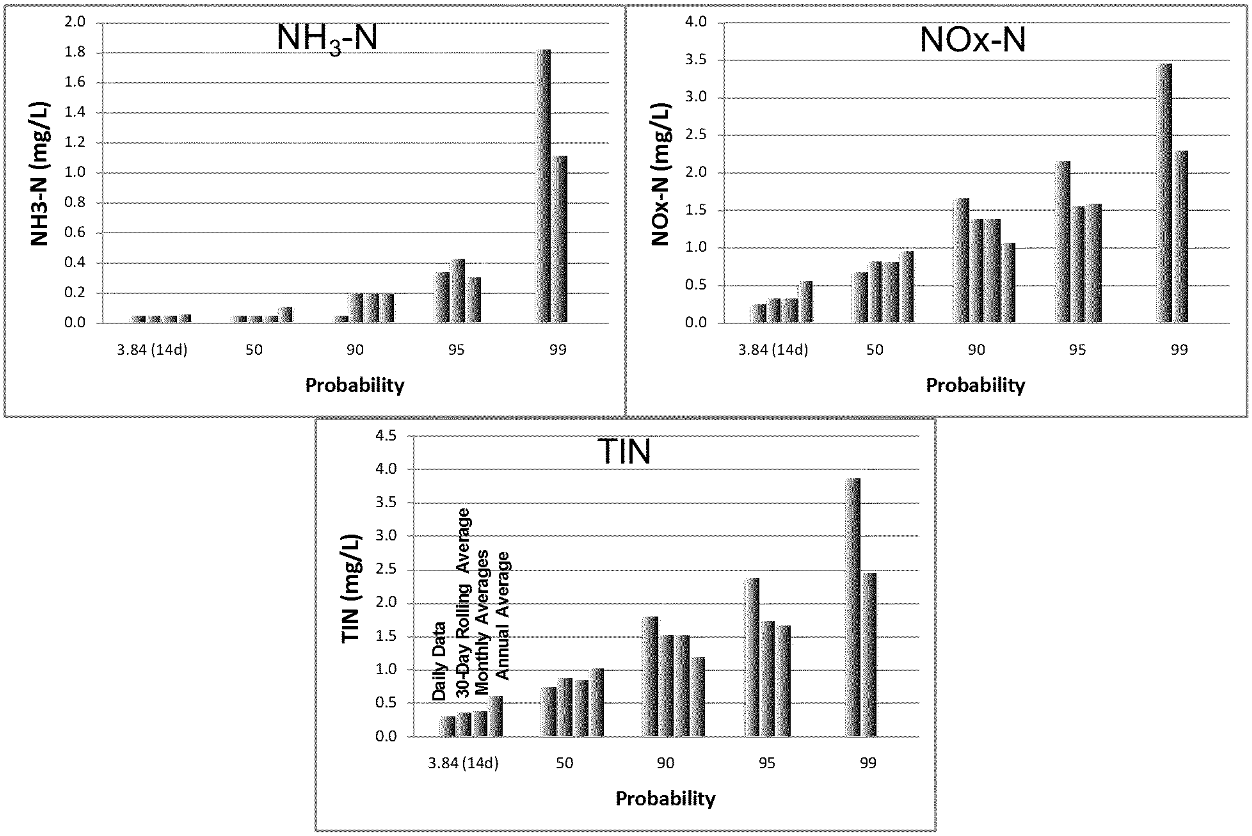

Figure 3-32. Probability Summary for Kalkaska Clean Water Plant.

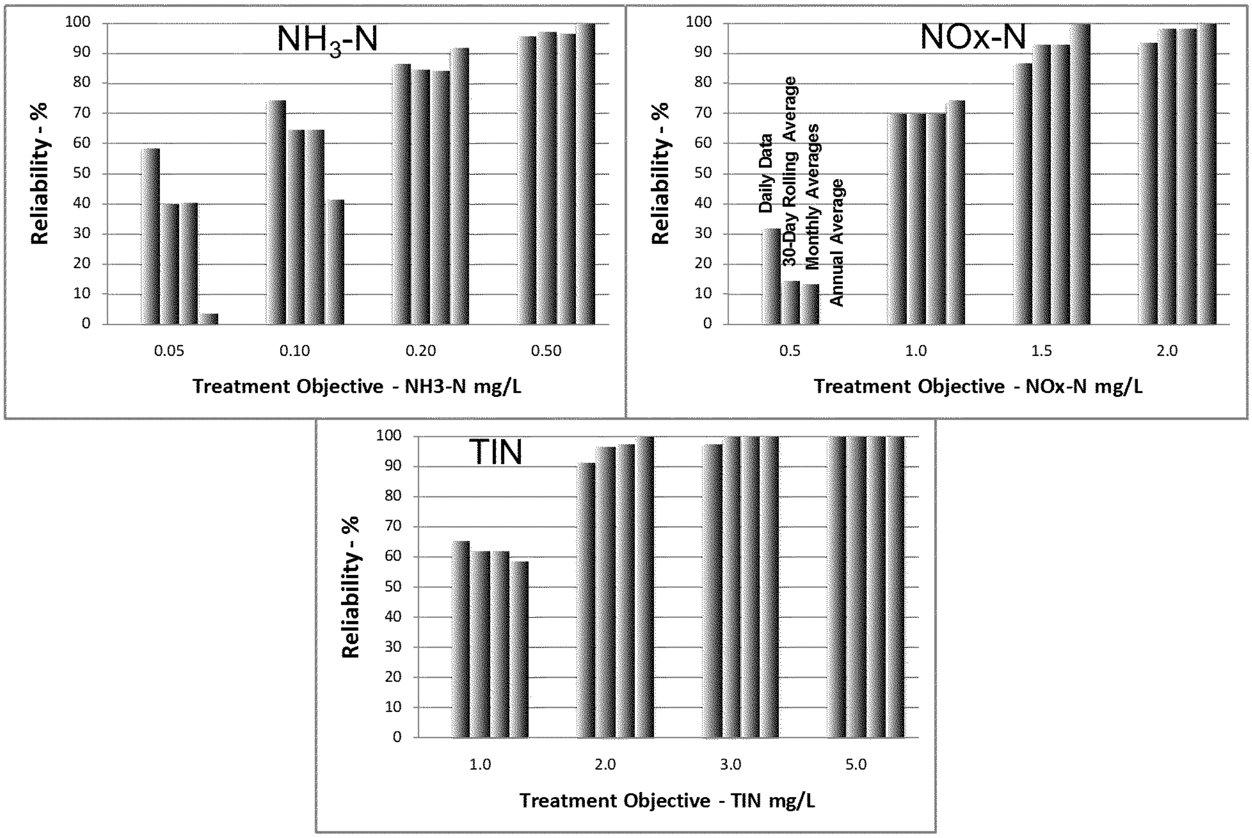

Figure 3-33. Reliability Summary for Kalkaska Clean Water Plant.
Note that the Reliability Calculations Assume that the Data are Log-Normally Distributed.

3.6.2 Littleton/Englewood, CO

The Littleton/Englewood Wastewater Treatment Plant is the third largest publicly owned treatment works (POTW) in the state of Colorado. The plant receives sewage from the cities of Englewood and Littleton, as well as from 21 connector districts within the 75 square mile service area of the cities. During the period analyzed, the design capacity was 36 million gallons per day (MGD) and the plant was treating an average of 23 MGD.

The Littleton/Englewood WWTP was placed online in 1977 as a 20 MGD pure oxygen activated sludge plant. The facility has undergone several expansions and upgrades. In 1991, as part of the master plan Phase 1a project construction converted the secondary system to the trickling filter/solids contact process (TF/SC). The pure oxygen system was replaced with fine bubble diffusers; dissolved air flotation thickeners were constructed that co-thicken primary sludge and WAS prior to anaerobic digestion; and chlorine and sulfur dioxide gas for chlorination/de-chlorination were replaced with sodium hypochlorite and sodium bisulfite. In addition, NTFs were installed to meet new effluent ammonia limitations. In 1999, construction for Phase 1b was completed (Figure 3-34). Table 3-56 contains the raw influent wastewater design parameters and average influent concentrations.

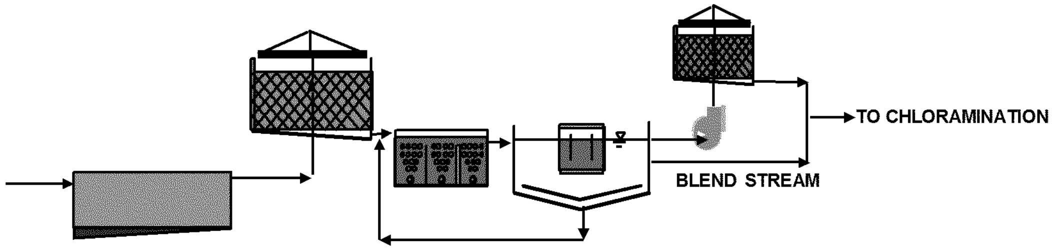

Figure 3-34. Littleton/Englewood Process Flow Diagram.

Table 3-56. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Littleton/Englewood WWTP from January 2002 Until December 2004.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	36	23.0	64
BOD_5 (mg/L)	200	257	82
$cBOD_5$ (mg/L)	N/A	179	N/A
TSS (mg/L)	180	204	72
Ammonia (mg/L)	26	24.8 [b]	61
TP (mg/L)	N/A	5.9 [b]	N/A
Temperature (°C)	N/A	18.6 [c]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Grit basin effluent concentration.
c. Average solids contact tank temperature.
d. N/A: Data not available or applicable.

Raw sewage from Englewood and Littleton flow into the plant separately, is measured, and then combines as it enters the headworks for screening. The flow is then pumped up to grit removal chambers. After grit removal, sewage flows by gravity to four primary clarifiers. Settled sludge slurry is continually withdrawn and is pumped to the DAFT. The TFs are biofilm reactor processes that convert soluble BOD_5 in the primary clarifier effluent into TF humus (biomass), reducing BOD_5 loading to downstream processes. Primary clarifier effluent flows by gravity to the trickling filter pump station. Two internal recycle streams are introduced to the flow at this point: the DAFT subnatant and ammonia-rich centrate return from the dewatering of anaerobic sludge. The flow is pumped up to the trickling filters. The trickling filters utilize plastic cross flow media and are covered and force ventilated. The flow rate is maintained at a steady rate which exceeds the plant influent flow so that there is always some degree of recycling. The solids contact tanks (SCT) are an integral part of the trickling filter/solids contact (TF/SC) biological treatment process. In this process the trickling filter effluent (TFE) is mixed with aerated solids in the SCTs to improve sludge settleability and to oxidize any $cBOD_5$ remaining in the TFE. Trickling filter effluent flows by gravity to the solids contact process where it is mixed with return solids just prior to entering five parallel SCTs. Detention times in the SCTs are typically 30 minutes to one hour. Air is provided to the SCTs utilizing multi stage centrifugal blowers and fine bubble diffusers. Dissolved oxygen meters are used to hold the DO level at a set point between 1.5 – 2.0 mg/L. There are five flocculator clarifiers for final sedimentation of the biological solids previously conditioned in the SCT process. The primary function of the final clarifiers is to condition the solids for improved settling and collect the settled biological solids for re-routing back to the SCT process. The final clarifier effluent is then routed to the NTF pump station. The return solids are pumped upstream of the SCTs and mixed with TFE prior to entering the SCTs. Waste sludge is pumped from this return stream and co-thickened in the DAFTs. Secondary clarifier effluent is pumped to three NTFs. The NTFs are specialized, fixed-film biological processes that convert soluble ammonium-nitrogen (NH_3-N) in the secondary clarifier effluent into nitrate-nitrogen (NO_3-N), plus a relatively small amount of NTF humus (biomass). They contain plastic cross flow media. To maintain a consistent hydraulic loading, the flow to the NTFs does not vary and, like the trickling filters, is always higher than the plant flow creating a recycle of NTF effluent back to the NTF pump station. A portion of NTF influent is bypassed around the NTFs and reintroduced into the NTF effluent. The volume of this bypass is controlled through SCADA utilizing a real time ammonia analyzer. A valve opens and closes to regulate the bypass flow to hold an ammonia target of 1.5-2.0 mg/L in the NTF effluent. This is critical in maintaining a chloramine residual in the disinfection process. The NTF effluent flows by gravity to the chlorine contact tanks (CCT). Sodium hypochlorite is utilized for chlorination and sodium bisulfite is used for de-chlorination. Both dosages are controlled using on-line measurement of oxidation reduction potential (ORP). Table 3-57 contains a summary of the discharge limits.

Table 3-57. Current NPDES Permit Limits as of October 2009 at the Littleton/Englewood WWTP.

Parameters	30-Day Average	7-Day Average	Daily Max
Flow (MGD)	36.3	N/A	N/A
$cBOD_5$ (mg/L)	20	30	N/A
TSS (mg/L)	30	45	N/A
Ammonia-N (mg/L)			
January	8.7	N/A	17.2
February	9.1	N/A	20.2
March	6.7	N/A	17.5
April	4.9	N/A	15.2
June	6.1	N/A	N/A
July	5.3	N/A	N/A
August	4.5	N/A	N/A
September	4.8	N/A	20.8
October	5.8	N/A	22.5
November	6.9	N/A	18.1
December	11.1	N/A	N/A
TIN (mg/L)	39.4	N/A	N/A

Note:
a. N/A: Data not available or applicable.

3.6.3 Utoy Creek, GA

The Utoy Creek WRC is one of the four wastewater treatment plants owned by the City of Atlanta, Georgia. It was upgraded in 2000 to reduce phosphorus concentrations discharged from the plant. It is rated to treat a maximum month flow of 44 MGD. Figure 3-35 is a schematic presentation of the major processes at the WRC. Table 3-58 contains the raw influent wastewater design parameters and average influent concentrations.

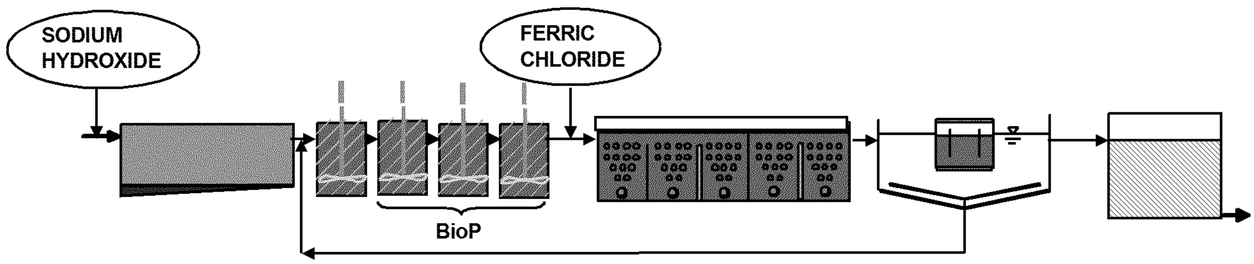

Figure 3-35. Utoy Creek Process Flow Diagram.

Table 3-58. Design and Average Raw Influent Concentrations and Percent of Design Loads for the Utoy Creek WRC from January 2005 Until December 2007.

Parameter	Raw Influent Design	Average Raw Influent	Percent of Design [a]
Flow (MGD)	36	26.5	74
$cBOD_5$ (mg/L)	120	103	63
COD (mg/L)	N/A	303	N/A
TSS (mg/L)	145	208	106
TKN (mg/L)	25	23.3	69
Ammonia (mg/L)	11.7	10.4	65
TP (mg/L)	3.2	3.4	77
Temperature (°C)	N/A	21.2 [b]	N/A

Note:
a. Percent of design is based on influent design loads (lbs./day) and average influent loads (lbs./day).
b. Average final effluent temperature.
c. N/A: Data not available or applicable.

Raw wastewater together with the recycles from dewatering centrifuges and the incinerator is discharged to the preliminary treatment processes which includes coarse bar screening, vortex grit removal, and 5-mm fine screening using rotary drums. Following preliminary treatment, screened influent flows into four primary clarifiers. Primary effluent is diverted to the biological system which consists of anoxic and anaerobic zones followed by aerobic zones. Flocculator clarifiers serve as secondary sedimentation basins and are provided with flocculation center wells and Towbro-type suction sludge removal systems. Secondary effluent is pumped to deep-bed mono-media filters followed by UV disinfection and cascade aeration before discharged to Chattahoochee River.

Solids processes consists of centrifugal thickening of waste activated sludge, followed by anaerobic digestion, thickening centrifuges and two incinerators of which one is operational. In addition, odor control facilities were constructed for control of odor generated from liquid and solids processes.

The current permit and the proposed permit limits (concentration limits) are shown in Table 3-59. The Utoy Creek WRC is required to meet year around monthly average ammonia limit of 1.8 mg NH_3-N/L with the proposed permit. That is about 91% reduction in ammonia levels during the period of December through March. Utoy Creek WRC is also required to reduce $cBOD_5$ by 50% during the December-April period and 67% reduction in TSS year around compared to current permit requirements.

Table 3-59. Current and Proposed NPDES Permit Limits as of October 2009 at Utoy Creek WRC.

Parameter	Monthly Average	Maximum Week	Daily
Flow (MGD)	40	60	N/A
Current Permit			
$cBOD_5$ (mg/L)			
Dec – Apr	16.4	24.6	36.9
May - Nov	15	22.5	33.75
TSS (mg/L)	30	45	67.5
Ammonia-N (mg/L)			
Dec – Mar	20.0	30.0	N/A
April	15.4	23.1	N/A
May	7.6	11.4	N/A
June	4.2	6.3	N/A
Jul – Aug	3.7	5.6	N/A
September	4.0	6.0	N/A
October	6.0	9.0	N/A
November	10.9	16.3	N/A
TP (mg/L)	0.64		
Proposed Permit			
$cBOD_5$ (mg/L)	8.2	12.3	18.45
TSS (mg/L)	10	15	22.5
COD (mg/L)	45	67.5	N/A
Ammonia-N (mg/L)	1.8	2.7	N/A
TP (mg/L)	0.5	N/A	N/A

Note:
a. N/A: Data not available or applicable.

3.7 Summary of Plant Processes

The following tables (Table 3-60 through Table 3-63) provide a brief overview of the primary, secondary, and tertiary treatment processes at each plant. The summaries also include the location and type of any chemical addition that occurs at each plant using a coding system that is described in Table 3-60.

The nitrogen and phosphorus removal plants are also categorized according to how nutrients are removed. The nitrogen removal plants are considered either, combined nitrogen removal, separate stage denitrification, or multiple stages for nitrification and denitrification. A combined nitrogen removal plant removes nitrogen in one single process, for example, a single sludge system such as a 4-stage Bardenpho that achieves both nitrification and pre and post denitrification all in the same activated sludge process. A separate stage plant has two separate processes, one for nitrification and one for denitrification. An example would be a plant that has an activated sludge process for nitrification and carbon removal followed by a deep-bed denitrification filter. A multistage plant utilizes several treatment processes to remove nitrogen. For example, a 4-stage Bardenpho process for nitrification and denitrification followed by a denitrification filter for additional nitrogen removal.

The phosphorus removal plants are categorized as either single stage, multistage, or little to no chemical addition. This system is based on how many chemical addition points a plant uses specifically for phosphorus removal. A multistage plant utilizes at least two different chemical addition points. The chemicals may or may not be the same at these plants. And they may be used to supplement biological phosphorus removal. A single stage plant utilizes only one chemical addition point and a little to no chemical addition plant relies on biological phosphorus removal. However, these plants may have the capability to periodically add chemicals to enhance treatment, but they do not add chemicals regularly.

Table 3-60. Process Summary Legend.

Code	Definition	Code	Definition
1	Primary treatment	C_M	Methanol
1C	Chemical added to primaries	C_{Fe}	Iron (Fe^{3+} or Fe^{2+})
1$_C$	Ability to add chemical to primaries but not added regularly	C_{Al}	Alum
2	Secondary treatment	C_F	Fermentate
2B	Secondary treatment with biological phosphorus removal	C_{Ac}	Acetic acid
2C	Chemical added to secondary treatment process	C_L	Lime
2$_C$	Ability to add chemical to secondary process but not added regularly	F	Suspended solids removal filters
3	Tertiary treatment	TF	Trickling filters
3C	Chemical added to tertiary process	NTF	Nitrifying trickling filters
3$_C$	Ability to add chemical to tertiary process but not added regularly	DF	Deep bed denitrifying filters
3F	Tertiary Filtration	UF	Ultrafiltration

Table 3-61. Process Summaries of Nitrogen Removal Plants.

Plant	Code	Primary Treatment	Secondary Treatment	Tertiary Treatment
River Oaks	$1C_{AI}$-$2C_{AI}$-$3C_{M}$-3F	Clarifiers, EQ	(3) Aeration Tanks in Series, Clarifiers	Denitrification Basins, Clarifiers, Dual Media Deep Bed Filters
Eastern WRF	$2B_{CAI}$-3F	None	5-Stage Bardenpho Carrousel, Clarifiers	ABW Filters
Parkway	1-2_{CAI}	Clarifiers	4-Stage Bardenpho, Clarifiers	None
Fiesta Village	$2C_{AI}$-$3C_{M}$DF	None	Oxidation Ditches, Clarifiers	Denitrification Filters
Western Branch	$2C_{M}C_{AI}$-3F	None	HRAS, Clarifiers, NAS, Clarifiers, DNAS, N_2 Stripping Channel, Clarifiers	Dual Media Gravity Filters
Scituate	2-$3C_{M}$DF	None	Aeration Tanks, Clarifiers	Denitrification Filters
Truckee Meadows	1-2-3NTF-$3C_{M}$-3F	Clarifiers	Aeration Basins, Clarifiers	Nitrifying Trickling Filters, Denitrifying FBRs, Dual Media Gravity Filters
Piscataway	1-$2C_{AI}$-3F	Clarifiers	Step Feed Biological Nutrient Removal, Clarifiers	Dual Media Gravity Filters
Tahoe-Truckee	1-$3C_{L}$-$3C_{M}$-3_{CAI}F	Clarifiers	HPOS, Clarifiers	Floc Basins, Chemical Clarifiers, Recarb Basins, Clarifiers, Recarb Basins, Ballast Ponds, BAF, Tertiary Filters, Disinfection, SAT

Table 3-62. Process Summaries of Phosphorus Removal Plants

Plant	Code	Primary Treatment	Secondary Treatment	Tertiary Treatment
Iowa Hill WRF	2-3C$_{Al}$-3F	None	Anaerobic Zones, Aeration Basins, Clarifiers, EQ	Fine Screening, BAFs, DensaDeg Chem P Removal, Continuous Backwash Upflow Sand Filters
F Wayne Hill [a]	1-2BC$_{Al}$-3C$_{Fe}$-3F	Clarifiers	Aeration Basins, Clarifiers, EQ	Chemical Clarifiers, Deep Bed Granular Media Filters
	1-2BC$_{Al}$-3C$_{Fe}$-3UF			Chemical Clarifiers, Ultrafiltration Membranes
Cauley Creek	2BC$_{Fe}$-3UF	None	Modified Johannesburg BNR	MBR
Clark County [a]	1C$_{Fe}$-2B-3C$_{Al}$F	Clarifiers	Anaerobic/Oxic Basins, Clarifiers	Dual Media Filters
	1C$_{Fe}$-2B-3C$_{Al}$-3F			Chemical Clarifiers, Dual Media Filters
Rock Creek [a]	1C$_{Al}$-2-3C$_{Al}$-3F	Clarifiers	Step Feed MLE Aeration Basin, MLE Aeration Basins, Clarifiers	Upflow Floc Blanket Clarifiers, Monomedia Gravity Filters
	1C$_{Al}$-2-3C$_{Al}$-3F		MLE Aeration Basins, Clarifiers	Chemical Clarifiers, Dualmedia Gravity Filters
Blue Plains	1C$_{Fe}$-2C$_{Fe}$-3C$_{M}$-3F	Clarifiers	Activated Sludge, Clarifiers	Nitrification and Denitrification Reactors, Clarifiers, Multimedia Filters
ASA	1$_{CFe}$-2C$_{M}$C$_{Fe}$-3C$_{Al}$-3F	Clarifiers	Step Feed Biological Reactor Basins, Clarifiers	Rapid Mix and Flocculation, Inclined Plate Settlers, Gravity Filters
Pinery	2BC$_{F}$-3C$_{Al}$F	None	5-Stage Bardenpho Process, Clarifiers, EQ	Trident Adsorption Clarifier-Filter Process
Kelowna	1-2B$_{CAl}$C$_{F}$-3F	Clarifiers, EQ	3-Stage Bardenpho Process, Clarifiers	Dual Granular Media Gravity Filters
Kalispell	1-2B$_{CAl}$-3F	Clarifiers, EQ	Modified UCT Process, Clarifiers	Gravity Sand Filters

Note:

a. These plants have two separate types of treatment trains.

Table 3-63. Process Summaries of Nitrification Reliability Plants.

Plant	Code	Primary Treatment	Secondary Treatment	Tertiary Treatment
Utoy Creek	1C$_{Fe}$-2BC$_{Fe}$C$_{Ac}$-3F	Clarifiers	Biological Nutrient Removal Process, Clarifiers	Deep Bed Monomedia Filters
Littleton/Englewood	1-2TF-3NTF	Clarifiers	Trickling Filters, Solids Contact, Clarifiers	Nitrifying Trickling Filters
Kalkaska	2BC$_{Fe}$	None	Eimco (C4 Bardenpho) Oxidation Ditches, Clarifiers	Rapid Infiltration Basins

3.8 Summary of Influent Flows and Loads

An evaluation of influent flows and loads was conducted for each plant during the specific period analyzed. For example, if a plant was analyzed from January 2005 to December 2007, the influent data correlated to the same time period from 2005 to 2007. Note some plants have high seasonal variability, so their stated design flows and loadings are based on maximum loading or maximum flow conditions. Thus, when calculating average flows and loads for a three-year period, these plants will appear to be below their design capacity. Figure 3-36 represents the average percent of design flow for which each plant was operating during the period analyzed. Generally the plants that were operating well below their design flow (e.g. F. Wayne Hill) recently performed upgrades and expansions. The majority of the plants were operating between 60-90% of their design flow.

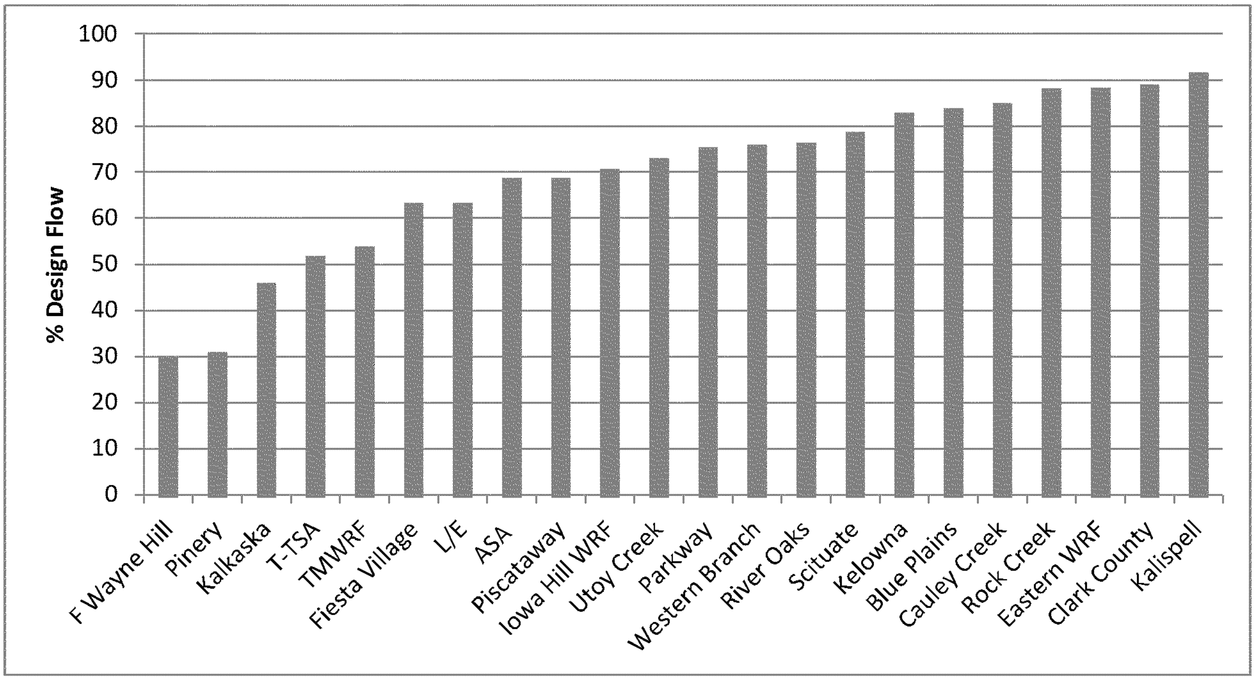

Figure 3-36. Percent of Average Daily Flows Versus Design Flows.

Figure 3-37 through Figure 3-39 summarize the average influent concentrations of TKN, ammonia, and TP for the plants where data was available. For example, several of the plants did not collect any raw influent data beyond flow and temperature. TKN values range from 20-45 mg/L as N, ammonia concentrations range from 10-35 mg/L as N, and phosphorus concentrations range from 2-9 mg/L as P. It should be noted that no two plants experienced the exact same flow or loads, further emphasizing that the results of this study cannot be translated directly to other plants.

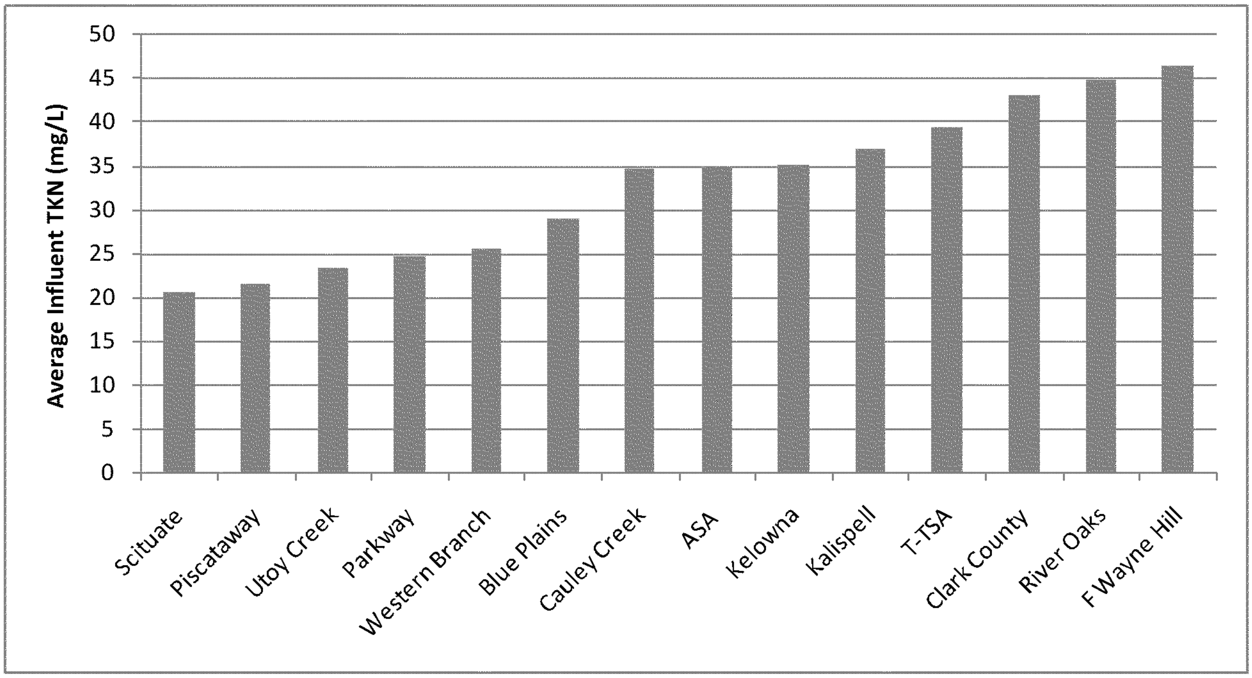

Figure 3-37. Average Influent TKN Concentrations.

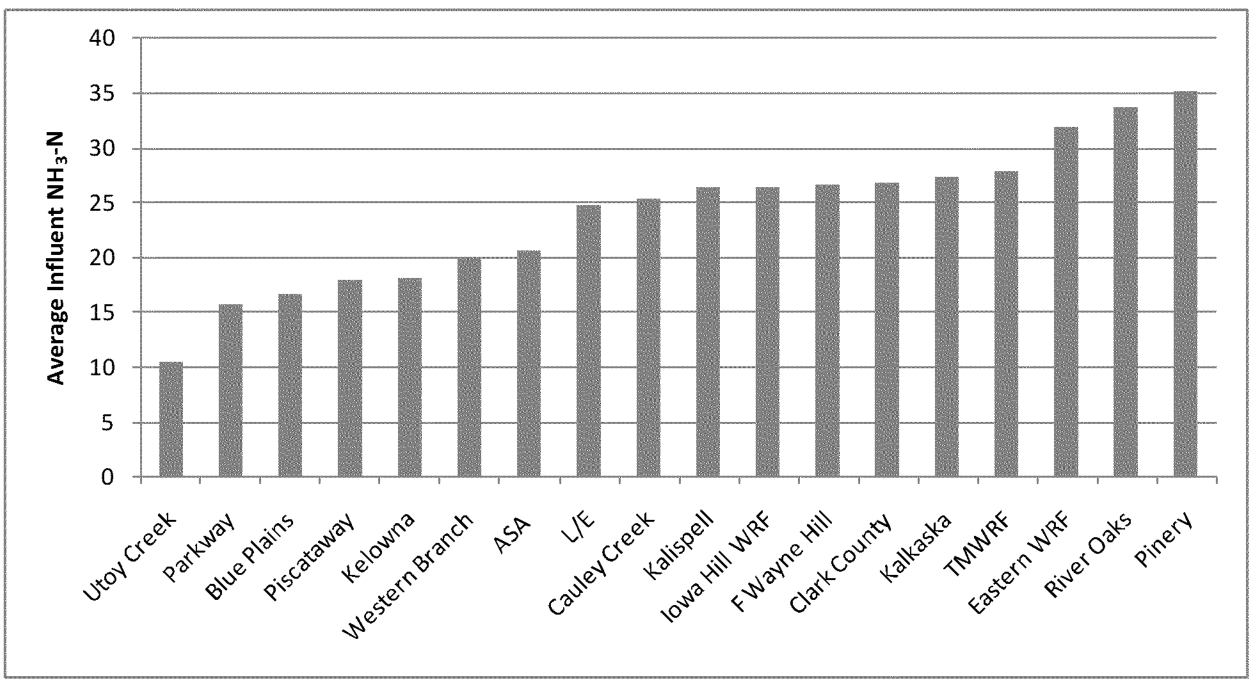

Figure 3-38. Average Influent NH_3-N Concentrations.

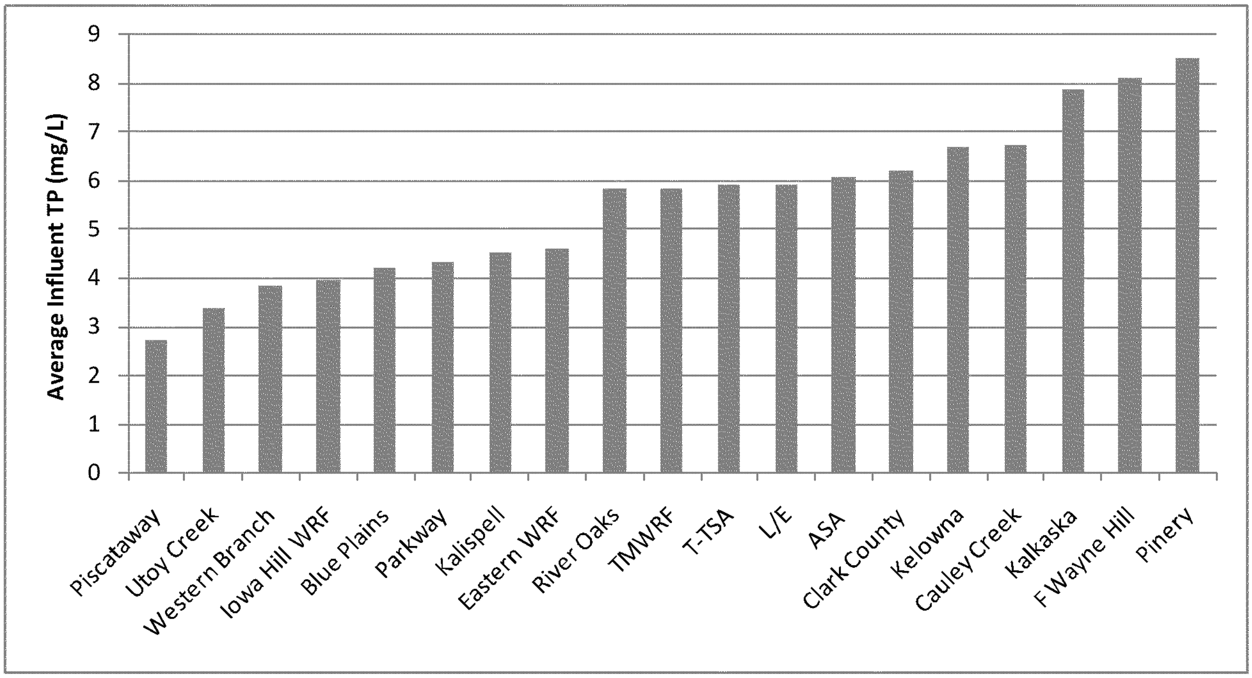

Figure 3-39. Average Influent TP Concentrations.

Figure 3-40 through Figure 3-42 summarize the average raw influent loads (lbs./day) compared to the influent design loads (lbs./day) provided for each plant for raw influent TKN, ammonia, and TP. Once again, several of the plants either did not provide influent data or did not routinely collect enough data for this evaluation. Only a few plants were above their influent design loads.

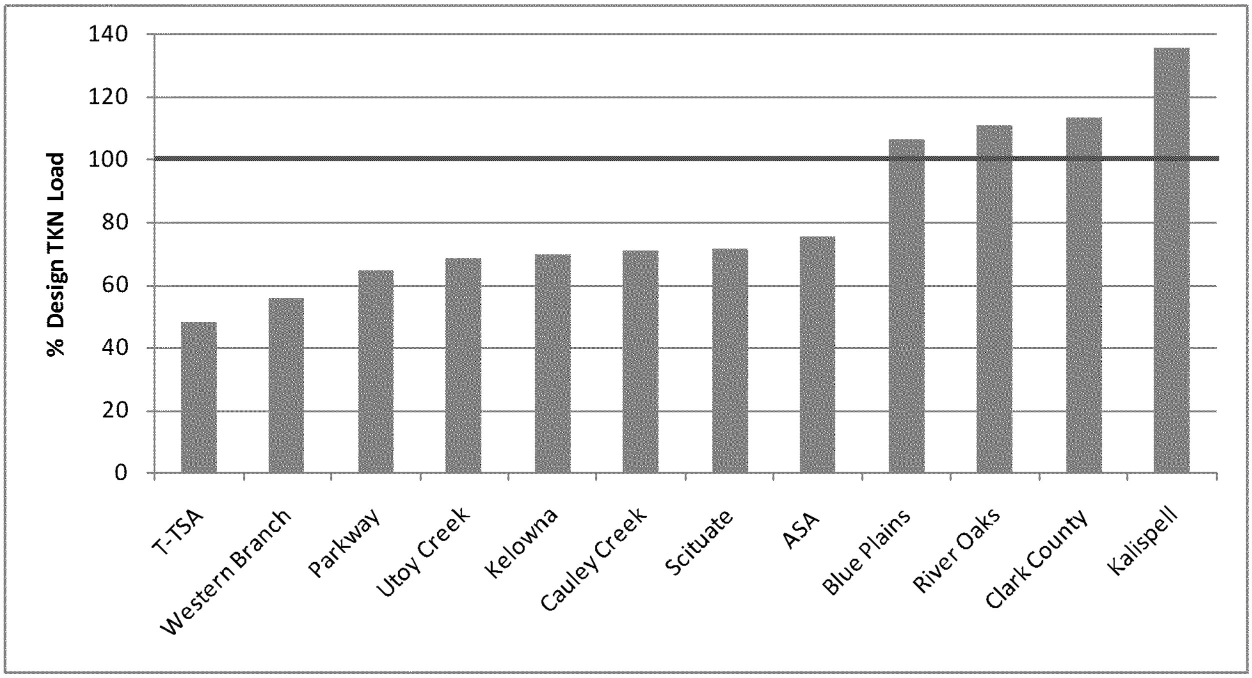

Figure 3-40. Percent Average Influent TKN Loads Versus Design Loads.

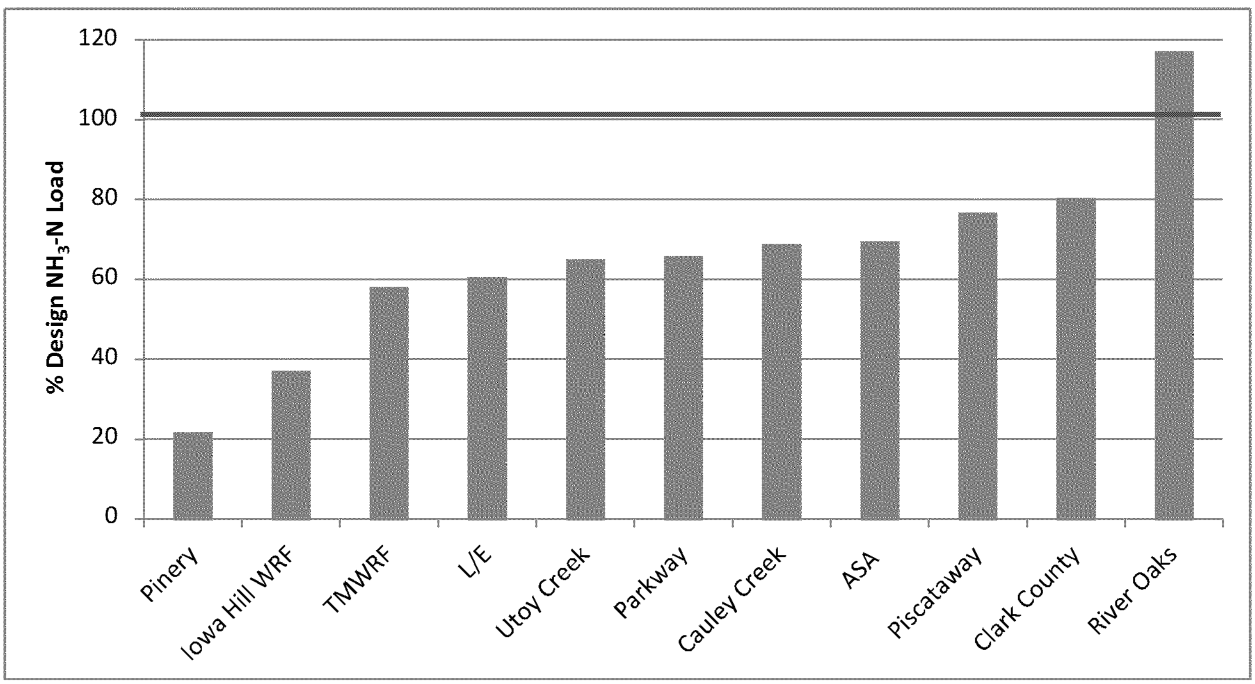

Figure 3-41. Percent Average Influent NH_3-N Loads Versus Design Loads.

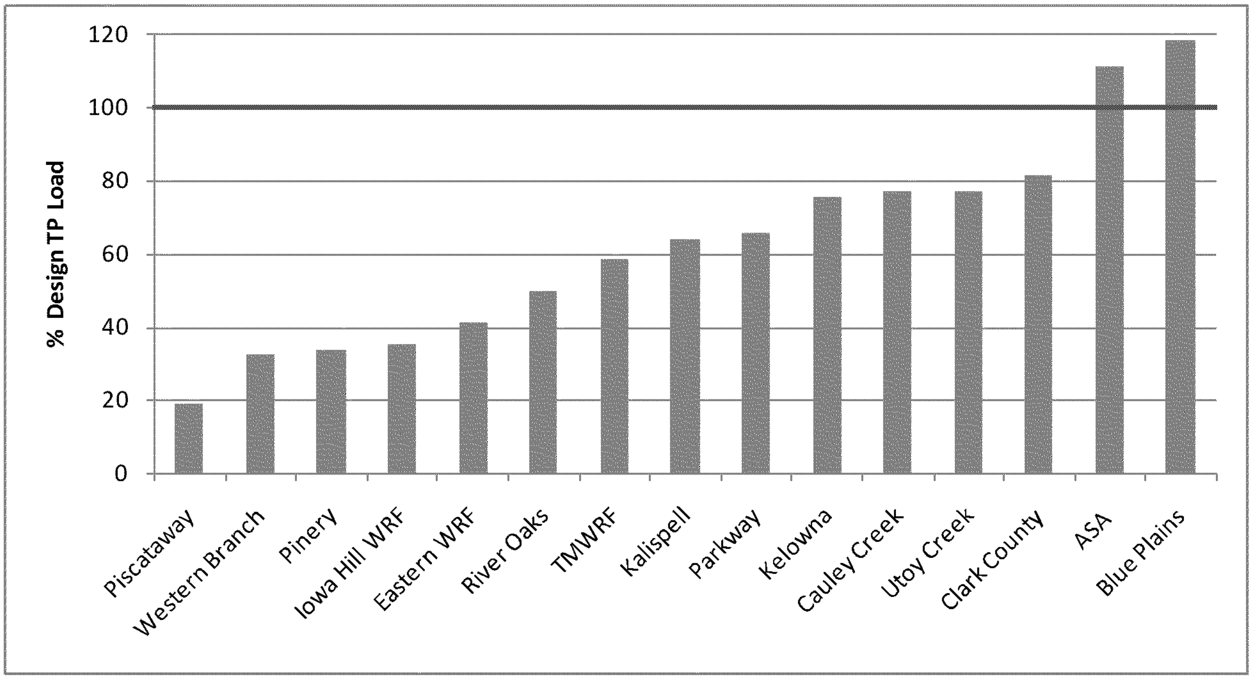

Figure 3-42. Percent Average Influent TP Loads Versus Design Loads.

Figure 3-43 summarizes the lowest 14-day rolling average temperature for each plant. These values represent the minimum value from a 14-day moving average using each plant's temperature dataset during the specific period of analysis River Oaks, Eastern WRF, and Fiesta Village did not collect temperature data during the survey period and temperature data was not provided for the F. Wayne Hill plant. Kalkaska, Littleton/Englewood, and Kelowna collected temperature data from their biological processes and Kalispell, Western Branch, and Pinery collected temperature data from their raw influent. All other plants reported the temperature of their final effluent.

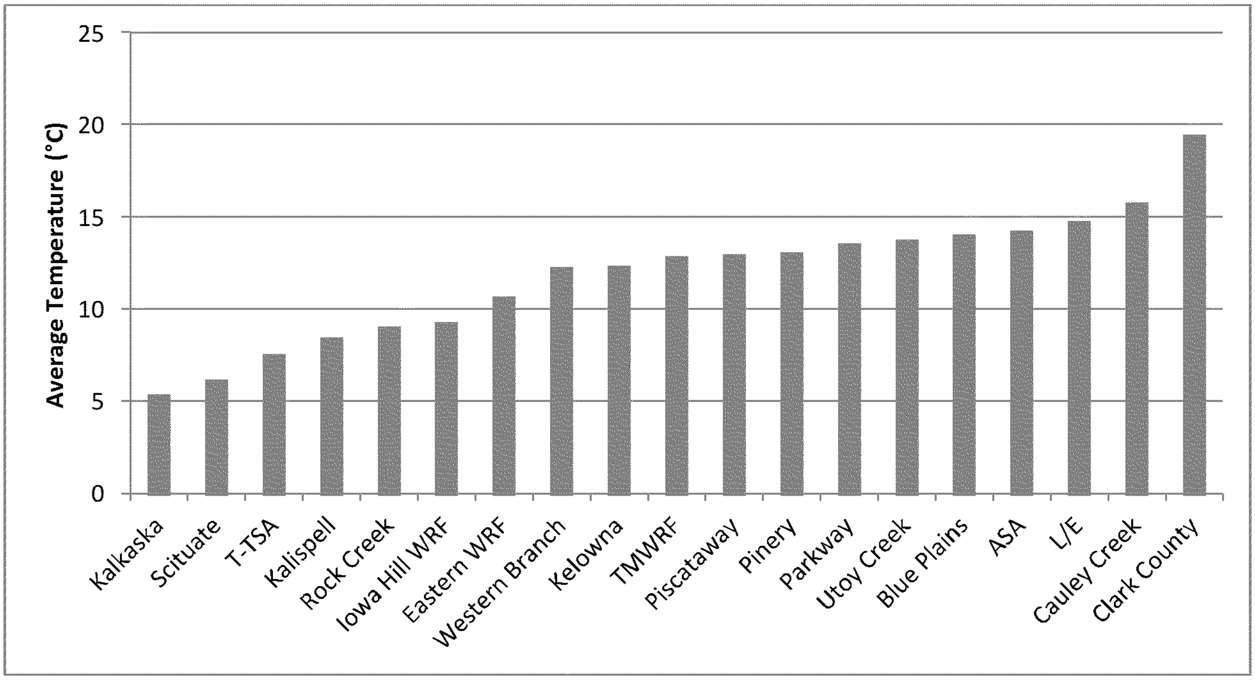

Figure 3-43. Lowest 14-Day Rolling Average Temperatures.

3.9 Summary of Chemical Dosages

An evaluation of chemical dosages was conducted for each plant during the specific period each plant was analyzed. All of the nitrogen removal plants that utilize supplemental carbon for denitrification use methanol. Table 3-64 and Table 3-65 summarize the average methanol dosages for each plant. The data is provided in two different units because several of the plants only collected a minimal amount of data. The units expressed in Table 3-64 are in terms of pounds of methanol as COD fed per pound nitrate removed in the denitrification process. The units expressed in Table 3-65 are gallons per day feed per MGD of plant flow.

Table 3-64. Average Methanol Dosages for the Nitrogen Removal Plants.

Plant	Chemical	Addition Point	Dosage (lbs MeOH as COD / lb NO_3-N Removed) [a]
River Oaks	Methanol	Denitrification Tanks	4.6
TMWRF	Methanol	Denitrifying FBRs	7.5
Western Branch	Methanol	DNAS Basins	3.9
Scituate	Methanol	Denitrifying Filters	5.5
T-TSA	Methanol	Denitrifying BAFs	4.5

Note:
a. Dosages calculated based on NO_3-N removed through particular treatment process where chemical is fed.

Table 3-65. Average Methanol Dosages for the Nitrogen Removal Plants.

Plant	Chemical	Addition Point	Dosage (gpd/MGD)
Fiesta Village	Methanol	Denitrifying Filters	40
River Oaks	Methanol	Denitrification Tanks	59
TMWRF	Methanol	Denitrifying FBRs	131
Western Branch	Methanol	DNAS Basins	69
Scituate	Methanol	Denitrifying Filters	43
T-TSA	Methanol	Denitrifying BAFs	94

Table 3-66 summarizes the chemical added, addition point, and dosages for the phosphorus removal plants that used chemicals for either supplementing biological phosphorus removal or chemical phosphorus removal on a regular basis. Chemical feed data was not provided for the Rock Creek plant. Rock Creek doses alum to their primary and tertiary clarifiers. Table 3-67 summarizes the average VFA concentrations in the fermentate added to the biological process for two of the plants that have fermenters. Fermentate data was not available for the Pinery plant.

Table 3-66. Average Chemical Dosages for the Phosphorus Removal Plants.

Plant	Chemical	Addition Point	Dosage (mol Al^{3+} or Fe^{3+} / mol Influent TP) [a]
Iowa Hill WRF	Alum	Tertiary Flash Mixer	2.92
Cauley Creek	$FeCl_3$	MBR Influent	3.06
Pinery	Alum	Filters	3.11
ASA	$FeCl_3$	Secondary Clarifiers	0.61
	Alum	Tertiary Clarifiers	0.44
F Wayne Hill	Alum	Secondary Clarifiers	0.12
	$FeCl_3$	Tertiary Chemical Clarifiers	0.03
	$FeCl_3$	Tertiary Chemical Clarifiers	0.03
Clark County	$FeCl_3$	Primary Clarifiers	0.27
	Alum	Tertiary Clarifiers (AWT)	0.13
	Alum	Tertiary Filters (CP)	0.13
Rock Creek	Alum	Primary Clarifiers	N/A
	Alum	Tertiary Clarifiers	N/A
Blue Plains	$FeCl_3$	Primary Clarifiers	0.66
	$FeCl_3$	Secondary Biological Reactors	0.33

Note:
a. Dosages calculated based on plant's raw influent TP.
b. N/A: Chemical feed data was not provided for the Rock Creek plant.

Table 3-67. Average VFA Dosages for the Phosphorus Removal Plants.

Plant	Chemical	Addition Point	Dosage (mg/L VFA)
Kelowna	Fermentate	Secondary Treatment Process	216
Kalispell	Fermentate	Secondary Treatment Process	246

CHAPTER 4.0

NITROGEN REMOVAL PLANTS

4.1 Reliability

The daily data reliability values that were calculated for each plant are summarized in Table 4-1. The TN reliability values were determined using each plant's lowest TN permit limit, regardless of the permit's averaging period (annually, monthly, or weekly). Thus, the daily data TN reliability should not be interpreted as the percent of the time the facility is in compliance with its permit. NH_3-N reliability values were calculated using an objective of 0.5 mg/L as N and NO_X-N reliability values were calculated using objectives of 0.5 and 2.0 mg/L as N. ON reliability values were calculated using objectives of 1.0 and 1.5 mg/L as N. The NH_3-N, NO_X-N, and ON objectives were not the treatment objectives of the individual facilities, but were used here to provide a common basis of evaluation. The plants were ranked according to TN reliability, but the plants could have been ranked according to any of the reliabilities that were calculated. The Kalkaska Clean Water Plant (CWP) was also included in this section because the plant focuses on TIN removal unlike the other nitrification reliability plants. It should be noted that the Kalkaska plant does not have a TN permit, but instead has a TIN permit limit. Note that the Tahoe-Truckee effluent values are for its BAF effluent and not its final effluent, which is measured after soil aquifer treatment.

Table 4-1. Summary of Daily Data Reliability Calculations for N Species.
(TN Based on the Plant Permit Limit, NH_3-N Based on a Constant Value of 0.50 mg/L,
NO_X-N Based on a Constant Value of 0.50 and 2.0 mg/L, and ON Based on Constant Value of 1.0 and 1.5 mg/L).

Plant	TN Permit (mg/L)/Averaging Period [a]	TN Reliability (%)	NH_3-N Obj. (mg/L)	NH_3-N Reliability (%)	NO_X-N Obj. (mg/L)	NO_X-N Reliability (%)	ON Obj. (mg/L)	ON Reliability (%)
Fiesta Village, FL	3/M	96.8	0.5	97.4	0.5/2.0	92.4/99.9	1.0/1.5	59.3/86.9
Parkway, MD	7/M	96.8	0.5	84.6	0.5/2.0	0.01/40.0	1.0/1.5	60.1/89.7
Kalkaska, MI	5 [b]/W	96.7 [b]	0.5	95.4	0.5/2.0	66.8/90.4	N/A	N/A
Piscataway, MD	8/M	95.8	0.5	83.8	0.5/2.0	0.22/38.5	1.0/1.5	91.2/98.2
River Oaks, FL	3/A	94.6	N/A	N/A	0.5/2.0	53.0/95.4	N/A	N/A
Western Branch, MD	3/M	90.3	0.5	92.8	0.5/2.0	35.6/95.1	1.0/1.5	82.0/96.1
Scituate, MA	4/M	87.9	0.5	76.1	0.5/2.0	56.8/95.0	1.0/1.5	26.7/58.3
Tahoe-Truckee, CA	3/M	80.2	0.5	89.2	0.5/2.0	69.3/98.6	1.0/1.5	0.14/24.3
Truckee Meadows, NV	2/M	75.2	0.5	92.8	0.5/2.0	95.2/99.9	1.0/1.5	10.0/70.5
Eastern WRF, FL	3/A	34.6	0.5	57.2	0.5/2.0 [c]	1.56/71.3 [c]	1.0/1.5	48.5/64.9

Note: a. A = Annual, M = Monthly, W = Weekly
b. Kalkaska has a TIN based permit.
c. Eastern WRF only collects NO_3-N data.
d. N/A: Data not available or applicable.

Based on the daily data reliability calculations it was determined that the Fiesta Village plant was the most reliable plant in terms of meeting its TN permit limit (Table 4-1). When comparing the nitrification reliability at the ammonia nitrogen objective of 0.5 mg/L as N, Fiesta Village was also the most reliable plant. The second best plant obtaining the 3.0 mg/L TN level of treatment was the River Oaks AWWTP.

4.2 Technology Performance Statistics

Table 4-2 shows the daily data TPS total nitrogen concentrations calculated from the nine plants that have nitrogen limits. The table also shows the process and permit limits for the facilities. The results show that the multistage (Fiesta Village) and separate stage (Western Branch and River Oaks) processes achieved the lowest daily data TPS-14d values. The control provided to plants with tertiary denitrification processes gives them the ability to reduce nitrate to low concentrations.

Table 4-2. Total Nitrogen Daily Data TPS Concentrations (mg/L) from Plants.

Plant	Process Code [a]	TN Permit (mg/L)/Averaging Period [b]	3.84% (14d)	50%	95%	3.84%/50%	95%/50%
Fiesta Village, FL	$2C_{Al}$-$3C_{M}DF$	3/M	0.25	1.03	2.71	0.25	2.62
Kalkaska, MI	$2BC_{Fe}$	5 [c]/W	0.31	0.75	2.40	0.41	3.20
Western Branch, MD	$2C_{M}C_{Al}$-3F	3/M	0.66	1.47	3.20	0.45	2.18
River Oaks, FL	$1C_{Al}$-$2C_{Al}$-$3C_{M}$-3F	3/A	0.78	1.45	2.92	0.54	2.01
Truckee Meadows, NV	1-2-3NTF-$3C_{M}$-3F	2/M	1.16	1.57	2.85	0.74	1.82
Scituate, MA	2-$3C_{M}DF$	4/M	1.21	2.37	4.22	0.51	1.78
Piscataway, MD	1-$2C_{Al}$-3F	8/M	1.30	3.00	8.00	0.43	2.67
Tahoe-Truckee, CA	1-$3C_{L}$-$3C_{M}$-$3_{CAl}F$	3/M	1.67	2.50	3.37	0.67	1.35
Eastern WRF, FL	$2B_{CAl}$-3F	3/A	2.08	3.64	8.56	0.57	2.35
Parkway, MD	1-2_{CAl}	7/M	2.10	3.40	6.40	0.62	1.88

Note:
a. See Chapter 3.0 for explanation.
b. A = Annual, M = Monthly, W = Weekly
c. Kalkaska has a TIN based permit.

The daily data TPS-14d concentration for the nine plants analyzed was typically 50-60% of the median performance. The exception was Fiesta Village, where the lowest achievable concentration was 25% of the median performance. The 95th percentile performance was between 1.8 and 2.5 times the median performance. Comparing the 95th percentile to the TPS-14d, there is consistently about a magnitude difference in these values for the plants operating at very low effluent TN. This substantial degree of variability should be recognized in the permitting and design process and is an important finding of this project.

In addition to the TN TPS values calculated in Table 4-2, daily data ON TPS-50% values were determined and compared to the daily data TN TPS-50% values (Table 4-3). A ratio of the two values was determined and plotted against the daily data TN TPS-50% values (Figure 4-1).

Both the table and figure demonstrate that as lower TN values are obtained, the effluent TN becomes more dominated by ON.

Table 4-3. Comparison of Daily Data ON and TN TPS Concentrations (mg/L) from Plants [a].

Plant	Process Code	Daily TN-50%	Daily ON-50%	ON-50% / TN-50%
Fiesta Village, FL	2C$_{AI}$-3C$_{M}$DF	1.03	0.90	0.87
Western Branch, MD	2C$_{M}$C$_{AI}$-3F	1.47	0.71	0.48
Truckee Meadows, NV	1-2-3NTF-3C$_{M}$-3F	1.57	1.32	0.84
Scituate, MA	2-3C$_{M}$DF	2.37	1.40	0.59
Tahoe-Truckee, CA	1-3C$_{L}$-3C$_{M}$-3$_{CAI}$F	2.50	1.70	0.68
Piscataway, MD	1-2C$_{AI}$-3F	3.00	0.51	0.17
Parkway, MD	1-2$_{CAI}$	3.40	0.90	0.26
Eastern WRF, FL	2B$_{Cal}$-3F	3.64	1.29	0.35

Note:
a. ON 50th percentile may not occur at the same time as TN 50th percentile.

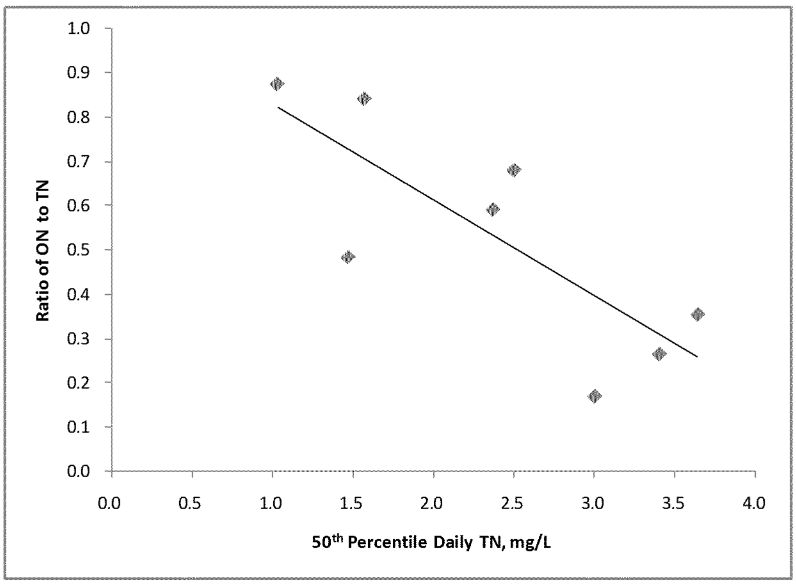

Figure 4-1. Ratio of ON and TN Daily Data TPS-50% Values.

4.3 Technology Evaluation

The project steering committee found that the monthly performance statistics were a logical bases for ranking technologies, partly because the majority of plants in the U.S. are governed by monthly permits and also because monthly values could be compared to an earlier survey of Florida plants that would allow more conclusive judgments to be drawn about technology rankings. Based on the 95th percentile of monthly average data the best performing plants in the study for nitrogen removal were the Fiesta Village and River Oaks plants, both located in Florida (Table 4-4). These warm climate plants were followed closely by plants in colder climates, the Truckee Meadows WRF and the Western Branch plant. The slightly superior performance of the two Florida plants may not only be due to the fact that they are in warmer climates, but also due in part due to the fact that both transport their solids offsite for subsequent processing. Both the Truckee Meadows and Western Branch plants process solids on site. Differences between these four plants are small considering their effluent TN varies on 95th percentile monthly basis only between 2.2 and 2.5 mg/L. Given their different designs, varying influent characteristics and climatic conditions, plus differing permit conditions, this small difference in effluent quality is likely not significant and the four of them as a group should be considered as the best performing plants in the US. A characteristic of all of them is that they have either a separate denitrification stage or a polishing step with methanol, which allows more precise control of effluent quality than the processes with combined flowsheets offer.

However, even at the level of performance exemplified by these four plants, the significant variability of the nutrient removal processes is evident from the ratios presented in Table 4-2. Comparing the TPS-14d to the 95th percentile (Table 4-2), it is clear that there is typically an order of magnitude difference in effluent concentration from ideal to reliable performance. This level of variability seems to be consistent for the best N removal plants in the country and must be recognized by the regulatory community.

Using the 95th percentile criterion to assess the technologies (Table 4-4), separate stage denitrification processes were able to satisfy or closely approach the maximum month criteria of 3.0 mg/L. With respect to combined processes, it was found at Parkway that with carbon addition the plant could achieve the monthly TN of 3.0 mg/L in the winter but not on a firm basis – but this was due to nitrification problems and inconsistent carbon addition and improper carbon addition control at the time of this data period. The Kalkaska CWP, a Bardenpho plant operating under very cold climatic conditions, was able to achieve a monthly TIN below the 3.0 mg/L TN criteria. If one assumes that Kalkaska has an average ON effluent concentration between 1.0 and 1.5 mg/L, then Kalkaska would be achieving approximately 2.7 to 3.2 mg/L TN on a 95th percentile basis. The Eastern Water Reclamation Facility was loaded more aggressively than other Florida Bardenpho plants and therefore not typical. The performance of Bardenpho plants with carbon addition from the earlier Florida survey achieved a 95th percentile monthly value of 3.5 mg/L, while better than the two plants we studied, is still above the two other nitrogen removal categories. The EPA survey (Kang et al., 2008) found max month values of 4.2-4.9 mg/L for other combined processes in northern climatic conditions, but no other Bardenpho processes with routine carbon addition were found in northern climates, so firm conclusions about the Bardenpho process performance under colder climatic conditions cannot be drawn at this time.

Table 4-4. 95th Percentile Monthly Average TN for Three Categories of Nitrogen Removal Plants.

Separate Stage	TN, mg/L	Combined	TN, mg/L	Multiple Stage	TN, mg/L
River Oaks, FL	2.3	Kalkaska, MI	1.7 [a]	Fiesta Village, FL (Denite Filter)	2.2
Western Branch, MD	2.4	Parkway, MD	5.1	5 A^2/O Plants with Denite Filters, FL [b]	3.0
Truckee Meadows, NV	2.5	Eastern WRF, FL	6.7		
Tahoe-Truckee, CA	3.1	Piscataway, MD	7.2		
Scituate, MA	3.8	10 Bardenpho Plants, FL [b]	3.5		
Howard F Curran, FL [b]	3.0				

Note: a. Kalkaska has a TIN based permit; assuming ON value of 1.0 to 1.5 mg/L, TN Value could be 2.7 to 3.2 mg/L.
b. Data for these plants are not included in this report and are from Jimenez et al., 2007.

Multiple stage N removal processes constitute ones where denitrification occurs both in an activated sludge step as well as in a polishing step such as in an effluent filter designed for denitrification. At least under the warm climatic conditions in Florida, they worked as well as separate stage processes (Table 4-4). Finally, no multiple stage processes with three years of operating data were found to study under colder climatic conditions, so the generality of the conclusions about multiple stage plants is uncertain at this point in time.

The remainder of the relevant 99th, 90th, and 50th percentile statistics for the plants in this study are shown in Table 4-5. When using annual rolling average on a 90th percentile basis as a criterion, all of the plants incorporating some separate denitrification step (TMWRF, River Oaks, Fiesta Village, Tahoe-Truckee, Western Branch, Scituate) were able to meet or come close to meeting the criterion of 3.0 mg/L TN. Out of the combined technology plants, only Kalkaska (considering adding 1.0 to 1.5 mg/L ON to Kalkaska's TIN annual rolling average) achieved the target of 3.0 mg/L TN on an annual 95th percentile basis. Piscataway, Parkway and Eastern were not able to meet the 3.0 mg/L annual TN criteria on a 90th percentile basis. It should be noted that there are many combined technology plants in that meet annual TN permits of 3.0 mg/L in the warm wastewater conditions of Florida.

Table 4-5. Relevant Statistics for Effluent Total Nitrogen Concentrations in the Study.

Plant	Process Code [a]	Daily, 99th percentile, mg/L	Annual, 50th percentile, mg/L	Annual, 90th percentile, mg/L
Truckee Meadows, NV	1-2-3NTF-$3C_M$-3F	3.64	1.67	1.94
Fiesta Village, FL	$2C_{Al}$-$3C_M$DF	3.86	1.22	1.65
Kalkaska, MI [b]	$2BC_{Fe}$	3.86	1.03	1.21
Tahoe-Truckee, CA	1-$3C_L$-$3C_M$-3_{CAl}F	3.91	2.53	2.62
River Oaks, FL	$1C_{Al}$-$2C_{Al}$-$3C_M$-3F	4.38	1.58	1.86
Western Branch, MD	$2C_MC_{Al}$-3F	6.14	1.71	1.86
Scituate, MA	2-$3C_M$DF	7.90	2.45	3.07
Parkway, MD	1-2_{CAl}	10.3	3.57	4.33
Piscataway, MD	1-$2C_{Al}$-3F	10.8	2.89	5.21
Eastern WRF, FL	$2B_{CAl}$-3F	14.2	4.26	4.47

Note: a. See Chapter 3.0 for explanation.
b. Values for Kalkaska are for TIN.

Another viewpoint about frequency of exceedances also must be made. 95th percentile monthly performance statistics are used in ranking nitrogen removal technologies (e.g., separate stage vs. combined nitrogen removal technologies). They should not be used to confirm that maximum month permit levels can be achieved for the plants studied, since by definition, they would be exceeded three months in a permit period, or 5% of the time. For example, while the 95th percentile monthly effluent TN concentration of the Truckee Meadows plant was 2.5 mg/L, the actual maximum month for the 36 month period analyzed was 3.2 mg/L. Similarly, the Martis Valley plant owned by T-TSA had a 95th percentile monthly effluent TN concentration of 3.1 mg/L, while the actual maximum month value for the 36 months of record was 3.4 mg/L.

4.4 Detailed Analysis of Nitrogen Removal Plant Performance

The following sections list the 30-day rolling average time series plots and daily data probability plots for all of the nitrogen removal plants except for the Truckee Meadows WRF since this plant was previously covered in Chapter 3.0. Each plant manager provided their insight on any data nuances or upsets in order to better understand what was happening at each plant during periods of elevated effluent nitrogen. General observations of the data are also provided for each plant.

4.4.1 River Oaks, FL

Historical operating data from April 2005 through March 2008 was analyzed. During this period no process upsets were identified that could have drastically changed the statistical analysis results. However, as indicated by the plant manager, the facility at the time was running at its capacity with monthly average events exceeding the rated capacity of the plant. This would most likely increase the effluent concentrations of the facility; however, it could not be isolated from the data set.

Comparing the 30-day rolling average TN (Figure 4-2) to the 3.0 mg/L annual average limit, it would appear that the treatment objective was met during the three years that the data spans. It can also be seen that the effluent TN is most significantly impacted by elevated nitrate and nitrite concentrations. This can also be observed in Figure 4-3 denoted by the slope of the NO_X-N data.

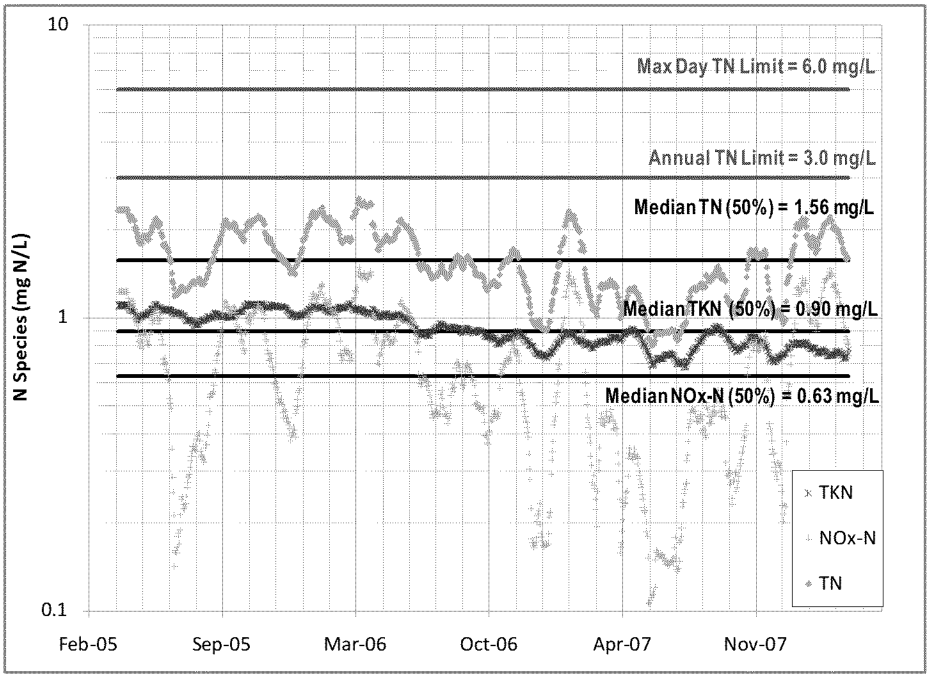

Figure 4-2. 30-Day Rolling Average Time Series Plot for the ROAWTP.

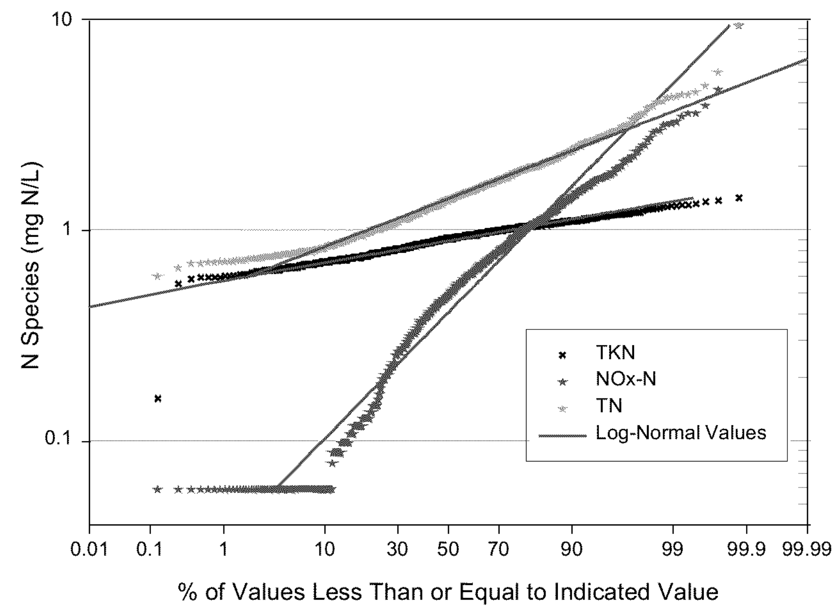

Figure 4-3. Daily Data Probability Plot for the ROAWTP.

4.4.2 Western Branch, WSSC, MD

During the January 2005 December 2007 period, the main operational upset reported by the plant manager was interruptions in methanol availability that impacted the plant's ability to maintain adequate denitrification. Effluent data from January 2005 through December 2007 was evaluated in terms of nitrogen species. During this period, methanol availability has been a major constraint during two occasions; July 2006 and October 2007 (5.6% of the entire period). However, in terms interpreting the plant effluent statistics, these events did not appear to affect the overall nitrogen concentrations at the facility. Based on the historical data, several independent events were observed in which the facility lost complete nitrification, and as a result effluent ammonia concentrations were elevated. However, these incidents did not always appear to affect the 30-day mean TN levels. The impact of effluent ammonia variability and spikes can be observed in Figure 4-4 and Figure 4-5.

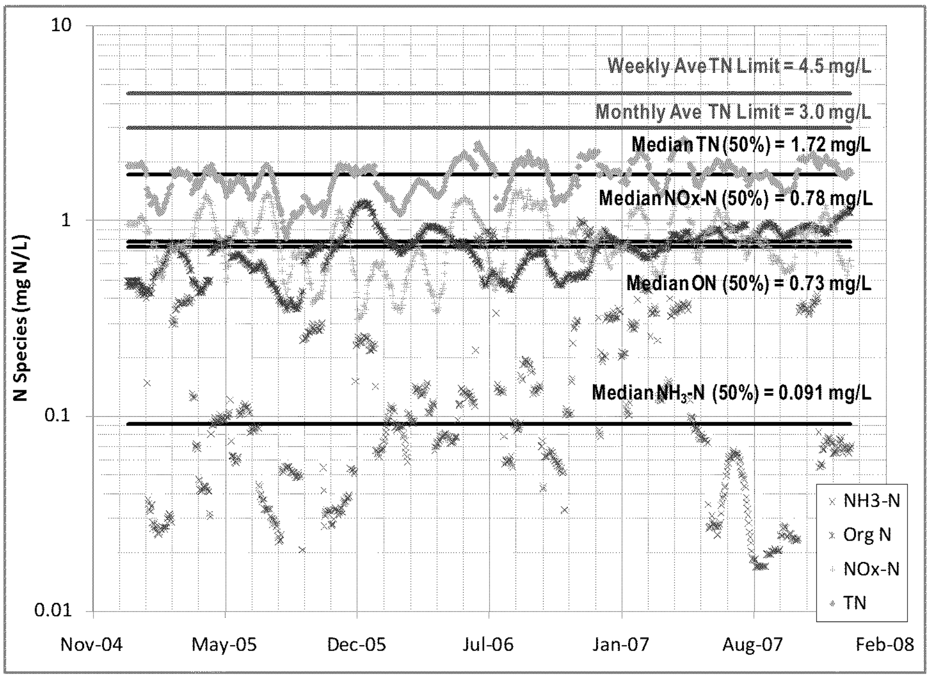

Figure 4-4. 30-Day Rolling Average Time Series Plot for the WBWWTP.

WERF

0007509

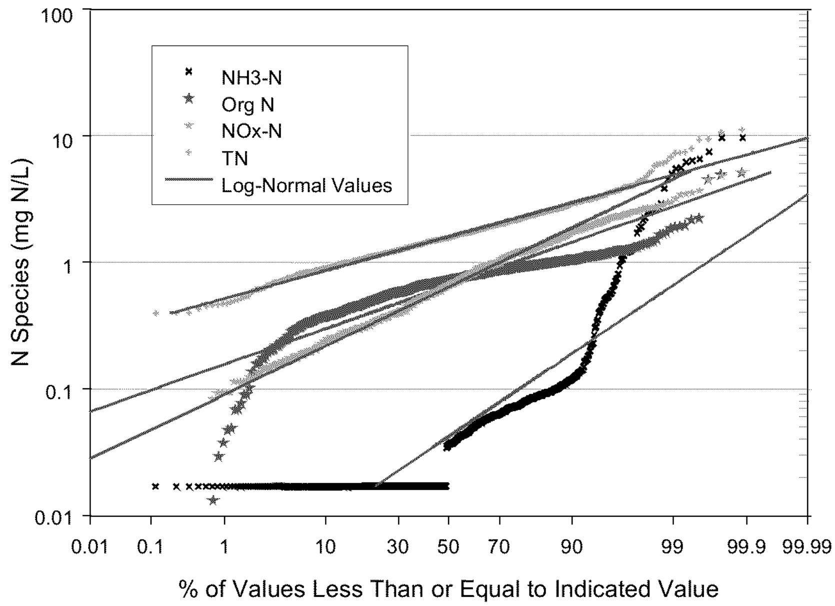

Figure 4-5. Daily Data Probability Plot for the WBWWTP.

4.4.3 Scituate, MA

During the January 2005 to December 2007 period, the Scituate WWTP experienced several episodes in which high nitrate levels were observed (Figure 4-6 and Figure 4-7). The facility relies on online nitrate analyzers at the filtration system. This system sends a signal to the methanol system to adjust the carbon addition. In January and October 2005 (3.6% of the entire period), the effluent nitrate sample line plugged up and caused a false reading in the monitoring system. The facility also tested an alternate carbon source between September 6 and November 28, 2005. The alternate carbon source increased the filamentous growth and higher levels of nitrates were observed especially in November 2005.

In high flow periods, the facility has the ability to bypass the excessive flows around the filtration system. Between October 15 and November 15, 2005, the plant's hydraulic capacity was exceeded resulting in bypass of unfiltered flow around the filters. Also during May 2006 and April 2007, the flows exceeded the plant's filtration capacity. During the three-year period, approximately 8.2% of the time the facility had to bypass unfiltered flow around the filtration system. In addition, although the reason is not clear, the plant went through a period between November 15 and December 15, 2006 in which NH_3-N and TKN concentration spikes were observed. These spikes were attributed by the plant manager to seasonal temperature variations and/or an error on their sampling protocols where the erroneous samples were sent for analysis. Starting with August 2007, a water treatment plant in the region started to send alum sludge to the facility. Increased nitrate levels after August 2007 were related to this event.

Based on the entire data set, the facility had effluent daily median and 30-day median TN values of 2.5 mg/L and 2.4 mg/L with maximum values of 15 mg/L and 5.1 mg/L, respectively. However, if the all these events identified previously were eliminated from the data set, the overall daily and 30-day median and maximum values would be approximately 2.3 mg/L (daily median) and 2.4 mg/L (30-day median) and 5.9 mg/L (max daily) and 3.9 mg/L (max 30-day), respectively.

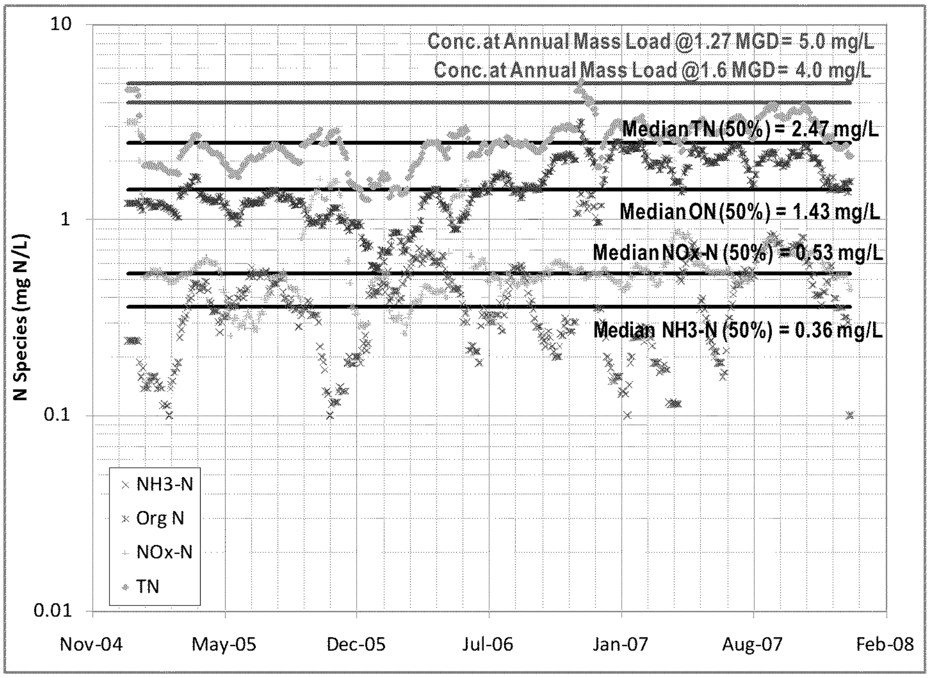

Figure 4-6. 30-Day Rolling Average Time Series Plot for the Scituate WWTP.

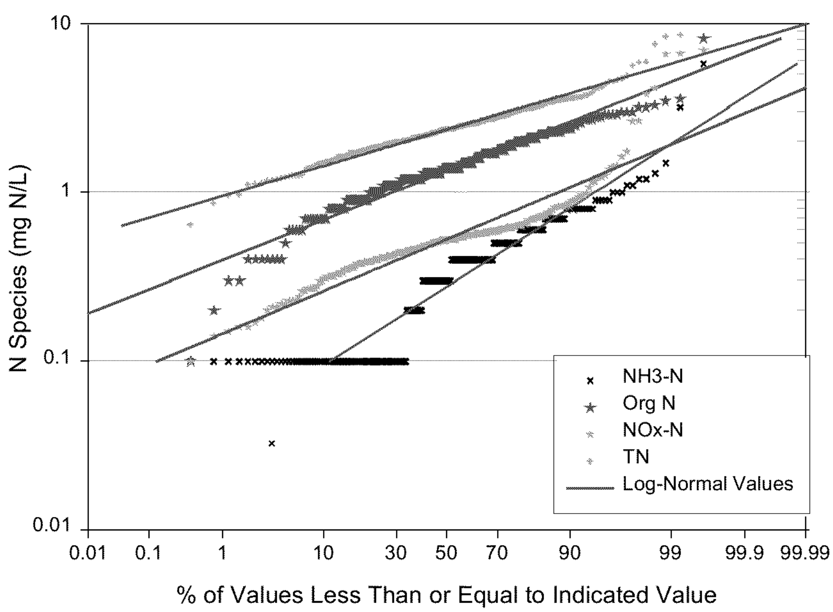

Figure 4-7. Daily Data Probability Plot for the Scituate WWTP.

WERF

0007511

4.4.4 Tahoe-Truckee Sanitation Agency, CA

Originally, the T-TSA plant data was analyzed from January 2007 until December 2009, however, in the early months of 2007 T-TSA's new BNR process was still undergoing final acceptance testing (FAT) where the system was being artificially loaded. Therefore an additional statistical analysis was completed using data from June 2007 until May 2010. From observation of Figure 4-8 and Figure 4-9 it is obvious that the final effluent TN is primarily composed of ON.

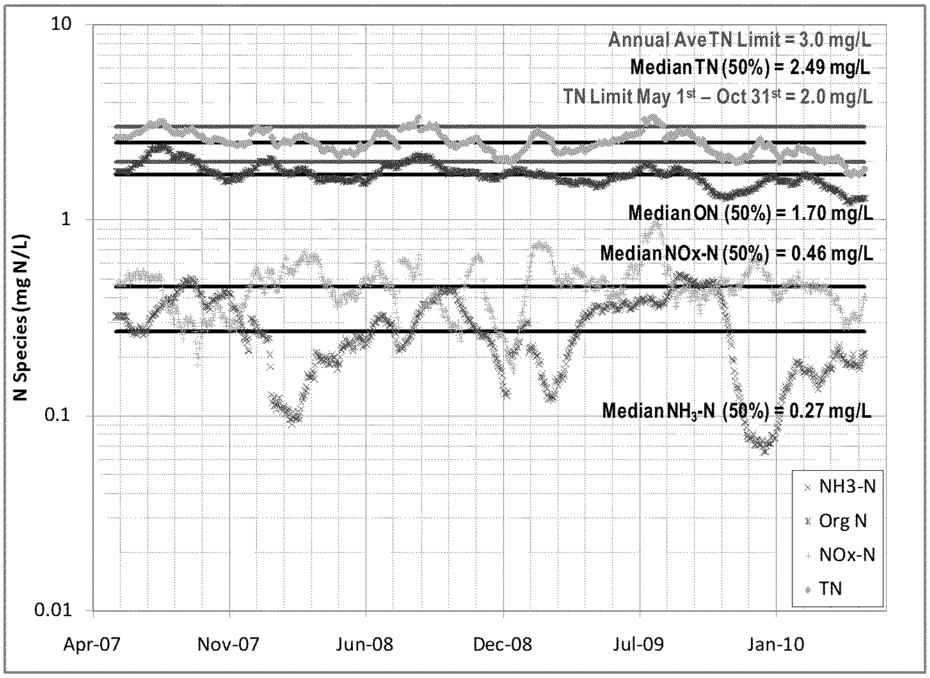

Figure 4-8. 30-Day Rolling Average Time Series Plot for Tahoe-Truckee.

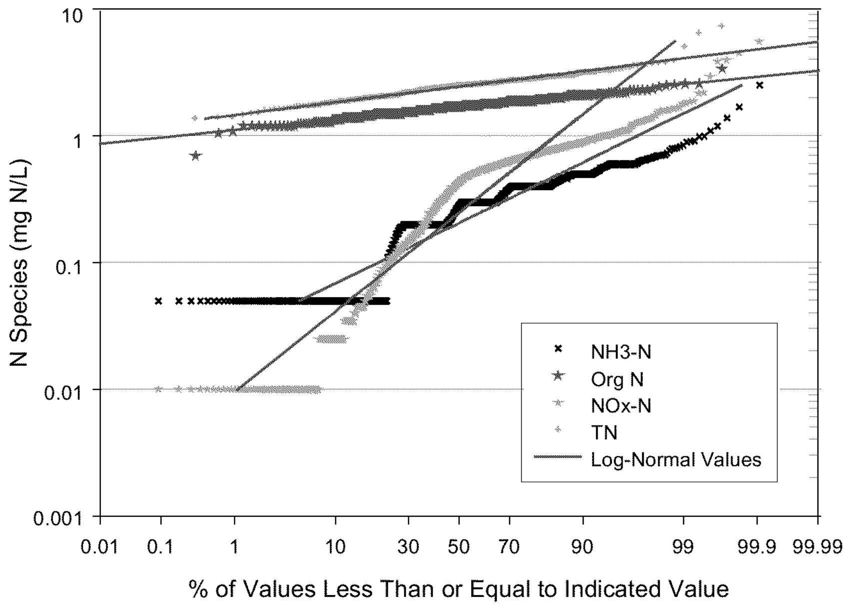

Figure 4-9. Daily Data Probability Plots for Tahoe-Truckee

4.4.5 Eastern Water Reclamation Facility, FL

During the January 2005 to December 2007 period, the Eastern plant experienced several challenges that affected the effluent quality of the facility including limited aeration capacity, reactors out of service during high loading conditions and a limited carbon in the wastewater for denitrification. Based on the plant operating data, the limited aeration capacity coupled with reactors out of service for maintenance affected the ability of the facility to fully nitrify, affecting the overall effluent TN concentrations at the facility (Figure 4-10 and Figure 4-11) Based on information provided by the plant manager, at least one reactor was out of service during March 10 through April 4, 2005 and from May 10 through June 19, 2007. This corresponds to approximately 65 days (or 5.3% of the time). Based on the entire data set, the facility has effluent daily median and 30-day median TN values of 3.7 mg/L and 3.9 mg/L with maximum daily and maximum 30-day values of 25 mg/L and 11 mg/L, respectively. However, if the periods where high effluent TN levels were experienced from reactors being out of service are eliminated from the data set, the overall daily median and 30-day median and maximum values would be approximately 3.6 mg/L (daily median) and 3.9 mg/L (30-day median) and 13 mg/L (max daily) and 7.8 mg/L (max 30-day), respectively. It should be noted this facility does not use supplemental carbon addition for denitrification.

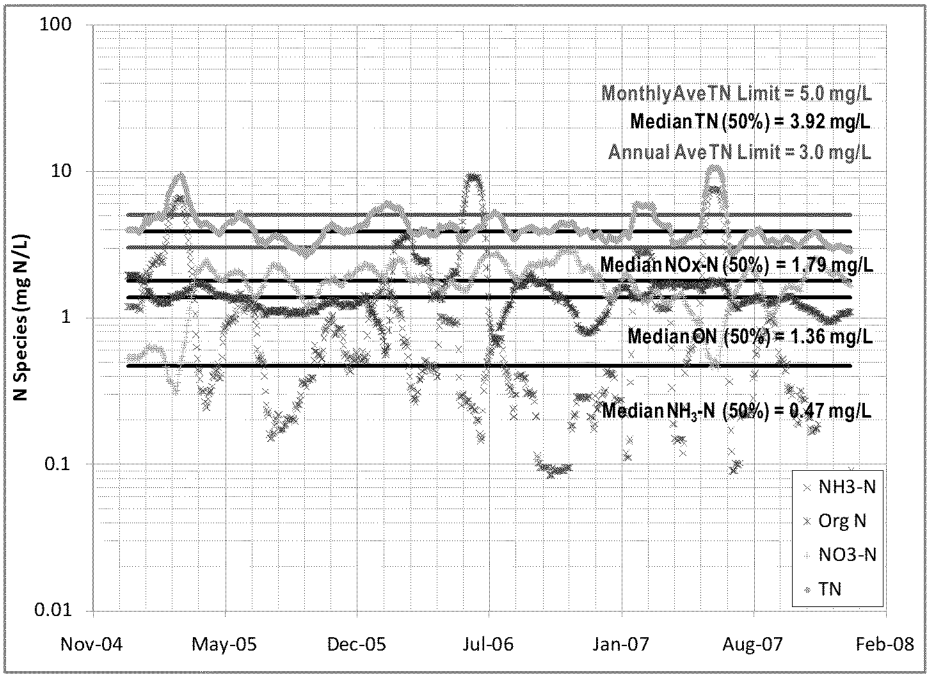

Figure 4-10. 30-Day Rolling Average Times Series Plot for the EWRF.

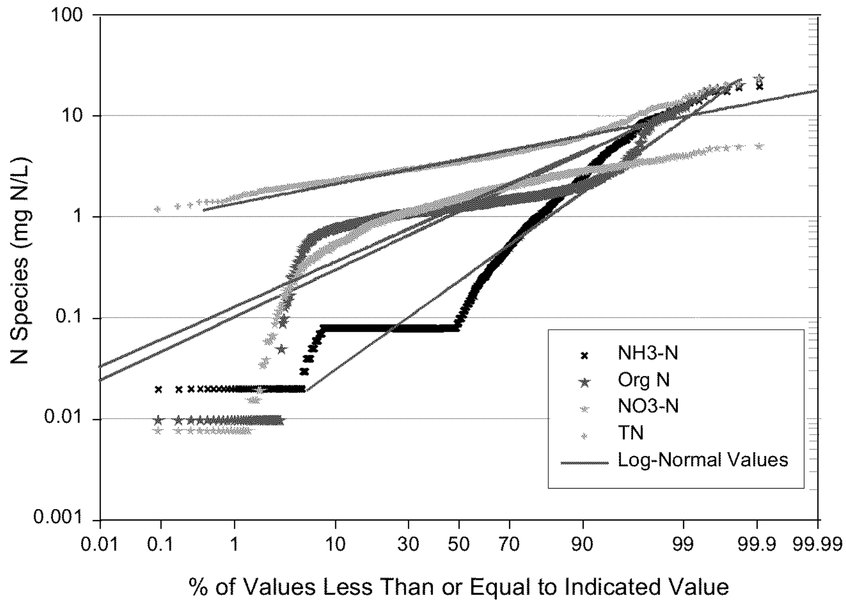

Figure 4-11. Daily Data Probability Plot for the EWRF.

4.4.6 Parkway, WSSC, MD

During the January 2005 to December 2007 period, based on information provided by the plant manager, one of the main issues related with the facility is the ability to maintain nitrification during the cold weather periods. Historical data provided indicates that during the period analyzed, complete nitrification was lost during cold weather conditions for 147 days (11.5% of the time) affecting the ability of the plant to meet low effluent TN values (Figure 4-12). Based on the entire data, the facility has effluent daily median and 30-day median TN values of 3.4 mg/L (daily) and 3.5 mg/L (30-day) with maximum daily and 30-day values of 13 mg/L (daily) and 9.1 mg/L (30-d), respectively. However, if the periods where nitrification was lost were eliminated from the data set, the overall effluent daily median and 30-day median TN values would be approximately 3.3 mg/L (daily) and 3.3 mg/L (30-day) with maximum daily and 30-day values of 8.1 mg/L (daily) and 5.0 mg/L (30-day), respectively. Figure 4-12 and Figure 4-13 emphasize the variability of nitrification at the Parkway WWTP.

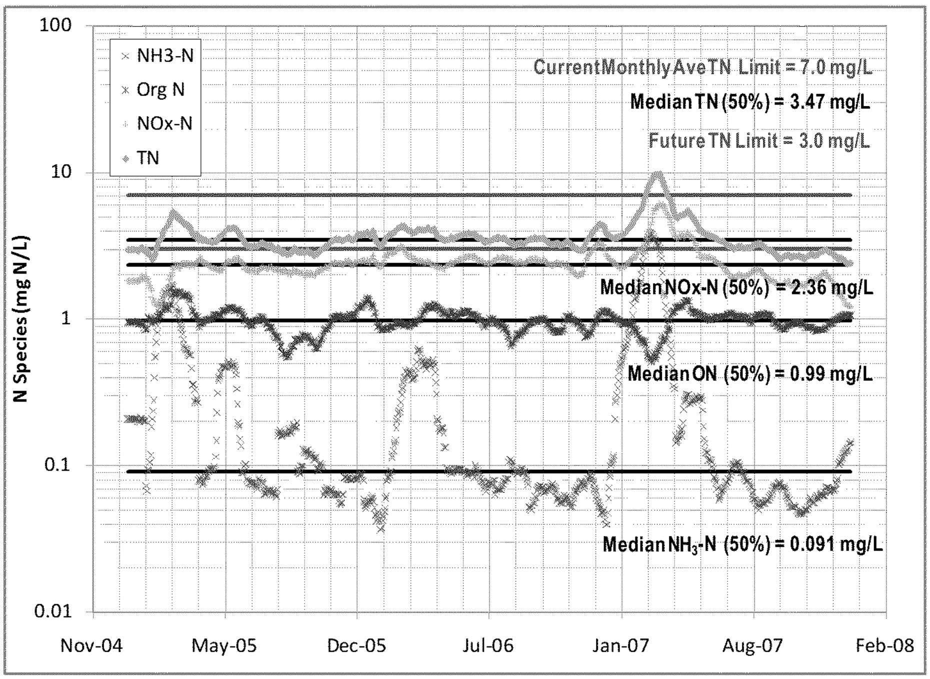

Figure 4-12. 30-Day Rolling Average Time Series Plot for the Parkway WWTP.

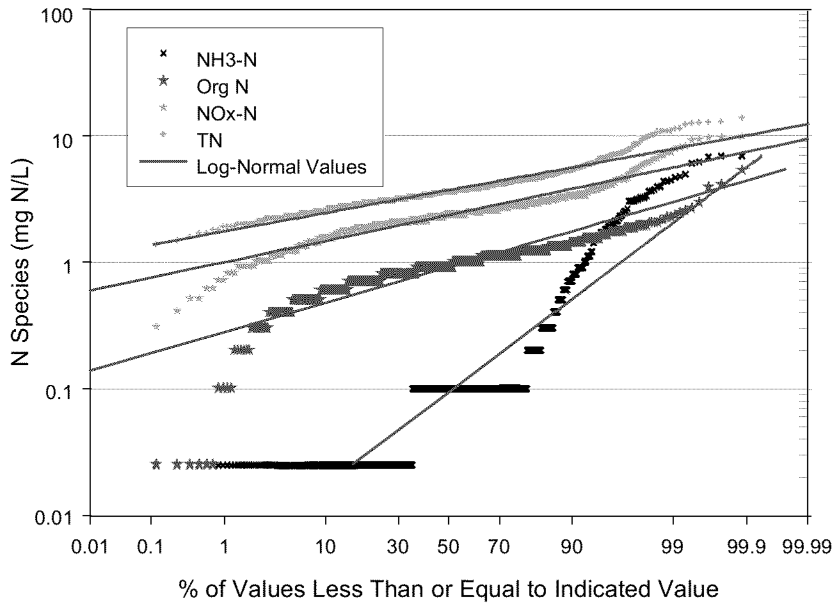

Figure 4-13. Daily Data Probability Plot for the Parkway WWTP.

4.4.7 Piscataway, WSSC, MD

During January 2005 through December 2007, several periods were identified with higher effluent NH_3-N concentrations (Figure 4-14 and Figure 4-15). Based on information presented by the plant manager, high effluent ammonia concentrations at the facility can be attributed to limited treatment capacity in the secondary process. During the 2005-2007 period, the plant experienced major issues maintaining nitrification, especially during the period of November 06 through May 07 (or 19.4% of the time). During this period, the 30-day median ammonia concentration increased from 0.065 mg/L to a maximum concentration of 6.0 mg/L. If this period is extracted from the dataset, the 30-day median value would be 0.017 mg/L. The average ammonia concentrations during the November 06 through May 07 period was 1.5 mg/L. No issues related to nitrate/nitrite levels were observed during this period.

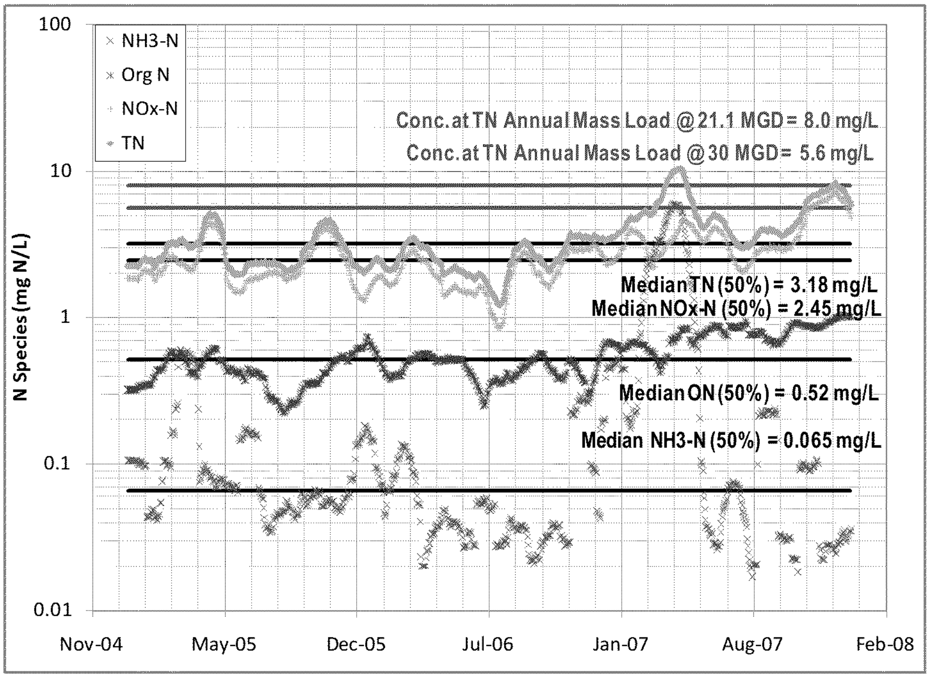

Figure 4-14. 30-Day Rolling Average Time Series Plot for the Piscataway WWTP.

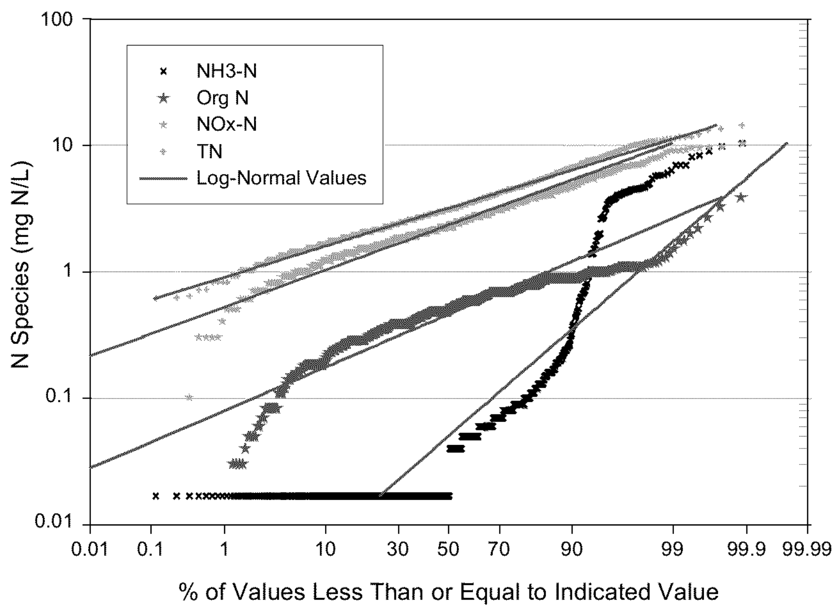

Figure 4-15. Daily Data Probability Plot for the Piscataway WWTP.

4.4.8 Fiesta Village, FL

Data from January 2005 through December 2007 was analyzed. Based on information provided by the plant manager, one of the main issues related to the facility is the seasonal flow variations due to population changes and the rainfall. Historical data provided indicates that peak flow conditions in March 2005, April 2006 and March 2007 correlates with higher effluent TN levels (Figure 4-16). Based on the entire data, the facility has effluent daily median and 30-day median TN values of 1.0 mg/L (daily) and 1.1 mg/L (30-day) with maximum daily and 30-day values of 6.5 mg/L (daily) and 2.8 mg/L (30-day), respectively. However, if the three months identified with peak flow conditions were eliminated from the data set, the overall daily median and 30-day median values would reduce to approximately 0.99 mg/L and 1.0 mg/L, respectively. Based on Figure 4-16 and Figure 4-17 the effluent TN is primarily ON indicating that the plant is capable of achieving almost complete nitrification and denitrification. The obvious deviations from this would be the wet weather imposed impacts indicated previously.

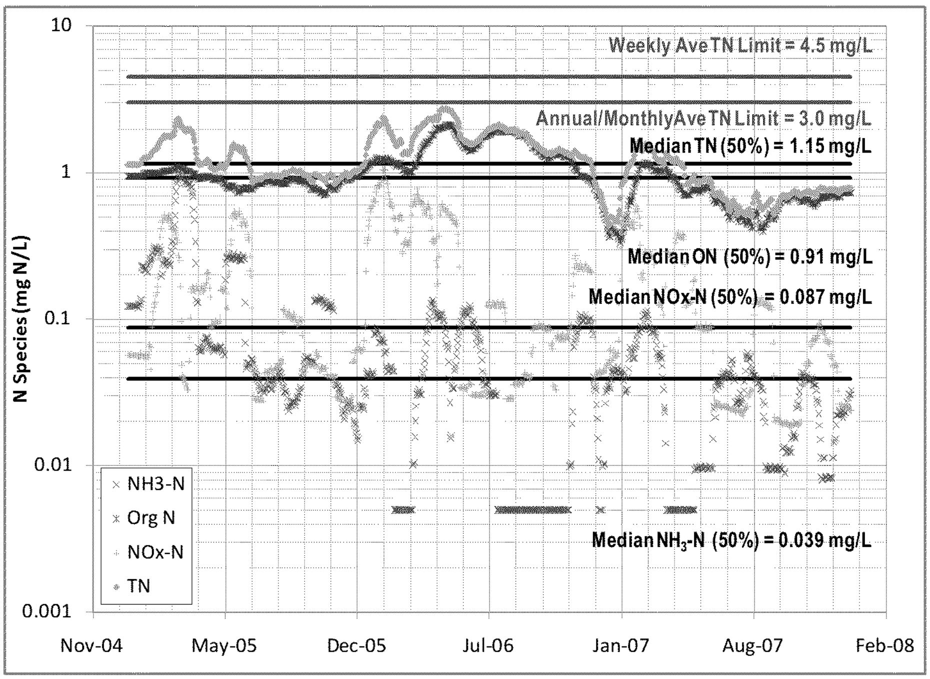

Figure 4-16. 30-Day Rolling Average Time Series Plot for the Fiesta Village AWTP.

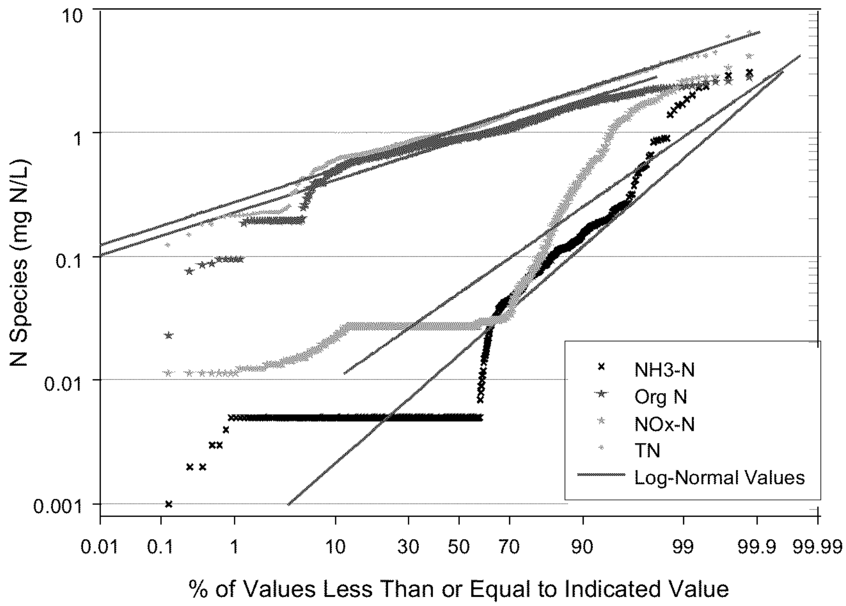

Figure 4-17. Daily Data Probability Plot for the Fiesta Village AWTP.

CHAPTER 5.0

PHOSPHORUS REMOVAL PLANTS

5.1 Reliability

The daily data reliability values that were calculated for each plant are summarized in Table 5-1. The TP reliability values were determined using each plant's lowest TP permit limit, regardless of the permit's averaging period (annual or monthly). Thus, the daily data TP reliability should not be interpreted as the percent of the time the facility is in compliance with its permit. OP reliability values were calculated using an objective of 0.1 mg/L as P. This objective was used as a common evaluation basis for all plants in the survey. The plants were ranked according to TP reliability, but the plants could have been ranked according to the OP reliabilities that were calculated.

Table 5-1. Summary of Daily Data Reliability Calculations for P Species.
(TP Based on the Plant Permit Limit and OP Based on Constant Value of 0.1 mg/L)

Plant	Process Code [a]	TP Permit (mg/L)/Averaging Period [b]	TP Reliability (%)	OP Objective (mg/L)	OP Reliability (%)
Kalispell, MT	1-2B$_{CAl}$-3F	1.0/M	100.0	N/A	N/A
ASA, VA	1$_{CFe}$-2C$_M$C$_{Fe}$-3C$_{Al}$-3F	0.18/M	98.5	0.10	100.0
Pinery, CO	2BC$_F$-3C$_{Al}$F	0.05/M	97.1	N/A	N/A
F. Wayne Hill, GA	1-2BC$_{Al}$-3C$_{Fe}$-3UF	0.13/M	96.8	N/A	N/A
Iowa Hill, CO	2-3C$_{Al}$-3F	0.05/A	95.7	N/A	N/A
Blue Plains, DC	1C$_{Fe}$-2C$_{Fe}$-3C$_M$-3F	0.18/A	93.5	0.10	88.8
Cauley Creek, GA	2BC$_{Fe}$-3UF	0.13/M	85.7	0.10	88.7
Clark County, NV	1C$_{Fe}$-2B-3C$_{Al}$-3F	0.14/M	81.7	0.10	91.0
Kelowna, BC	1-2B$_{CAl}$C$_F$-3F	0.25/A	78.7	0.10	86.4
Rock Creek, OR	1C$_{Al}$-2-3C$_{Al}$-3F	0.10/MM	72.3	0.10	92.6

Note:
a. See Chapter 3.0 for explanation.
b. A = Annual, M = Monthly, MM = Monthly Median
c. N/A: Data not available or applicable.

Given that it has the highest concentration in its permit, the Kalispell plant was the most reliable plant in the survey. However, considering the rest of the plants with lower permit levels, ASA's AWTF was the most reliable plant with a TP reliability of 98.5%. However, this could be compared to the reliability of the two plants with TP permit limits of 0.05 mg/L TP, with the Pinery plant with a TP reliability of 97.1% and the Iowa Hill WRF having a TP reliability of 95.7%. The lower reliability of the latter two plants reflects their lower permit limits. Since

Kalispell, Pinery, F. Wayne Hill, and Iowa Hill do not collect OP data, no definitive conclusion can be drawn from the OP reliability data.

5.2 Technology Performance Statistics

Table 5-2 shows the daily data TPS total phosphorus concentrations calculated from the ten plants that reported phosphorus data. The table also shows the process and permit limits for the facilities. The results show that the two stage chemical addition, often in combination with EBPR, produced low effluent concentrations. This is also true for single stage chemical addition coupled with EBPR or for single stage tertiary chemical addition with high chemical dosages (Iowa Hill). And two of the plants (Iowa Hill and Blue Plains) were able to achieve ideal performance for TP of less than 0.01 mg/L (see 3.84% or 14d column in Table 5-2).

Table 5-2. Total Phosphorus Daily Data TPS Concentrations (mg/L) from Plants.

Plant	Process Code [a]	TP Permit (mg/L)/Averaging Period [b]	3.84% (14d)	50%	95%	3.84%/50%	95%/50%
Iowa Hill, CO	$2\text{-}3C_{Al}\text{-}3F$	0.05/A	0.004	0.012	0.045	0.33	3.8
Blue Plains, DC	$1C_{Fe}\text{-}2C_{Fe}\text{-}3C_{M}\text{-}3F$	0.18/A	0.005	0.070	0.180	0.07	2.6
Pinery, CO	$2BC_{F}\text{-}3C_{Al}F$	0.05/M	0.013	0.023	0.045	0.58	2.0
F. Wayne Hill, GA	$1\text{-}2BC_{Al}\text{-}3C_{Fe}\text{-}3UF$	0.13/M	0.020	0.040	0.110	0.50	2.8
Rock Creek, OR	$1C_{Al}\text{-}2\text{-}3C_{Al}\text{-}3F$	0.10/MM	0.025	0.065	0.210	0.38	3.2
ASA, VA	$1_{CFe}\text{-}2C_{M}C_{Fe}\text{-}3C_{Al}\text{-}3F$	0.18/M	0.025	0.050	0.120	0.50	2.4
Cauley Creek, GA	$2BC_{Fe}\text{-}3UF$	0.13/M	0.040	0.080	0.160	0.50	2.0
Clark County, NV	$1C_{Fe}\text{-}2B\text{-}3C_{Al}\text{-}3F$	0.14/M	0.045	0.081	0.201	0.55	2.5
Kalispell, MT	$1\text{-}2B_{CAl}\text{-}3F$	1.0/M	0.050	0.100	0.230	0.50	2.3
Kelowna, BC	$1\text{-}2B_{CAl}C_{F}\text{-}3F$	0.25/A	0.090	0.150	0.324	0.60	2.2

Note:
a. See Chapter 3.0 for explanation.
b. A = Annual, M = Monthly, MM = Monthly Median; Permit limits are shows only as an indication of the requirement under which the plant operates. Permits requirements varies – for example Rock Creek operates under a monthly median permit; DC Water operates under an annual limit

The daily data TPS-14d concentrations for the ten processes analyzed are typically 40 to 50% of the median performance. The exception is Blue Plains and Iowa Hill, where the lowest achievable limit is 10-33% of the median performance.

The 95th percentile performance is typically between two and three times the median performance. Iowa Hill reports nearly four times the median, respectively. Iowa Hill had the lowest daily data TPS-50% value.

The phosphorus performance variability TPS-95%/TPS-50% ratio seems to show a relationship to the median value, increasing as the median value decreases.

5.3 Technology Evaluation

As for TN removal, technologies were rated upon the effluent quality on a monthly average basis. The best performing plant for phosphorus removal was the Iowa Hill plant, in Colorado (Table 5-3). As a class, single stage chemical addition processes for TP removal outperformed multiple stage processes (Table 5-3 and Table 5-4), but often at the expense of higher chemical dosages. The lowest TP values were found at the Iowa Hill plant with its tertiary ballasted sedimentation process. It is notable that the level of chemical addition at this plant was higher than at any other (alum 100 to 300 mg/L, sodium hydroxide, 80 to 100 mg/L), which is the major factor contributing to its very low effluent TP levels. It is not known if this reflects technological performance superiority over the MBR (Cauley Creek), as this may just reflect differing effluent requirements and chemical dosing practices rather than real technological superiority of the technology applied at Iowa Hill. For instance, the MBR in the EPA survey (Kang et al., 2008) shows the Lone Tree MBR plant, CO at a max month TP of 0.038 mg/L, which is very close to Iowa Hill's value. However, the Lone Tree MBR plant database was very limited in terms of the operational period compared to the plant records evaluated in this investigation, so the results may not be comparable. The five multiple stage plants (Table 5-3) were very similar in performance on a 95th percentile basis for maximum month conditions. Again, these technologies might have performed closer to the Iowa Hill plant's performance if their effluent requirements had demanded higher chemical dosages. When considering all of the plants, only the Iowa Hill, F. Wayne Hill, ASA, and Pinery plants could meet the TP criterion of 0.1 mg/L for maximum month conditions on a reliable basis (95th percentile), but all of them did much better on an annual average basis (see the annual 90th percentile column in Table 5-4). The performance of the two plants reliant almost exclusively on biological phosphorus removal, Kelowna and Kalispell performed exceptionally well, but not at the same levels as those that either were reliant on chemical addition or a combination of biological phosphorus removal with chemical addition to a tertiary step.

Table 5-3. 95th Percentile Monthly Average TP for Three Categories of Phosphorus Removal Plants.

Multiple Stage Chemical Addition	TP, mg/L	Single Stage Chemical Addition	TP, mg/L	Little or No Chemical Addition	TP, mg/L
F. Wayne Hill, GA	0.0902	Iowa Hill WRF, CO	0.0306	Kalispell, MT	0.168
ASA, VA	0.101	Pinery, CO	0.0363	Kelowna, BC	0.217
Clark County, NV	0.153	Cauley Creek, GA	0.116		
Rock Creek, OR	0.151				
Blue Plains, DC	0.161				

And a viewpoint about frequency of exceedances also must be presented. 95th percentile monthly performance statistics are used in ranking TP removal technologies (e.g., single stage vs. multiple stage technologies). They should not be used confirm that maximum month permit levels can be achieved for the plants studied, since by definition, they would be exceeded three months in a permit period, or 5% of the time. For example, while the 95th percentile monthly effluent TP concentration of the Iowa Hill plant was 0.03 mg/L, the actual maximum month for the 36 month period analyzed was 0.07 mg/L. Similarly, the ASA plant had a 95th percentile monthly effluent TP concentration of 0.10 mg/L, while the actual maximum month value for the

36 months of record was 0.12 mg/L. And the Kelowna plant had a 95th percentile value of 0.22 mg/L, while the actual maximum monthly value was 0.87 mg/L.

Table 5-4. Relevant Statistics for Effluent Total Phosphorus Concentrations in the Study.

Plant	Daily, 99th percentile, mg/L	Annual, 50th percentile, mg/L	Annual, 90th percentile, mg/L
Pinery, CO	0.062	0.025	0.026
Iowa Hill, CO	0.084	0.018	0.026
F. Wayne Hill, GA	0.161	0.052	0.061
ASA, VA	0.161	0.056	0.067
Blue Plains, DC	0.262	0.079	0.11
Cauley Creek, GA	0.282	0.086	0.093
Clark County, NV	0.335	0.097	0.11
Kalispell, MT	0.359	0.124	0.13
Rock Creek, OR	0.516	N/A	N/A
Kelowna, BC	0.846	0.158	0.22

Note:
a. N/A: not available; Rock Creek was only analyzed during dry months as they do not have a wet season TP limit. Therefore, annual 50th and 90th percentiles were not calculated.

5.4 Detailed Analysis of Phosphorus Removal Plant Performance

The following sections list the 30-day rolling average time series plots and daily data probability plots for all of the phosphorus removal plants except for the Clark County WRF since this plant was previously covered in Chapter 3.0. Each plant manager provided their insight on any data nuances or upsets in order to better understand what was occurring at each plant during periods of elevated effluent phosphorus. General observations of the data are also provided for each plant.

5.4.1 Iowa Hill Water Reclamation Facility, CO

From January 2005 to December 2007, several process upsets were experienced at the facility; however, no single event could be isolated where process upsets impacted the quality of the effluent. Based on information presented by the plant manager most of the upsets experienced at the facility were related to the chemical feed system (Figure 5-1). Furthermore, the seasonal variations in flows and loads have a significant effect on phosphorus removal. Figure 5-2 contains the daily data probability plot for the Iowa Hill WRF.

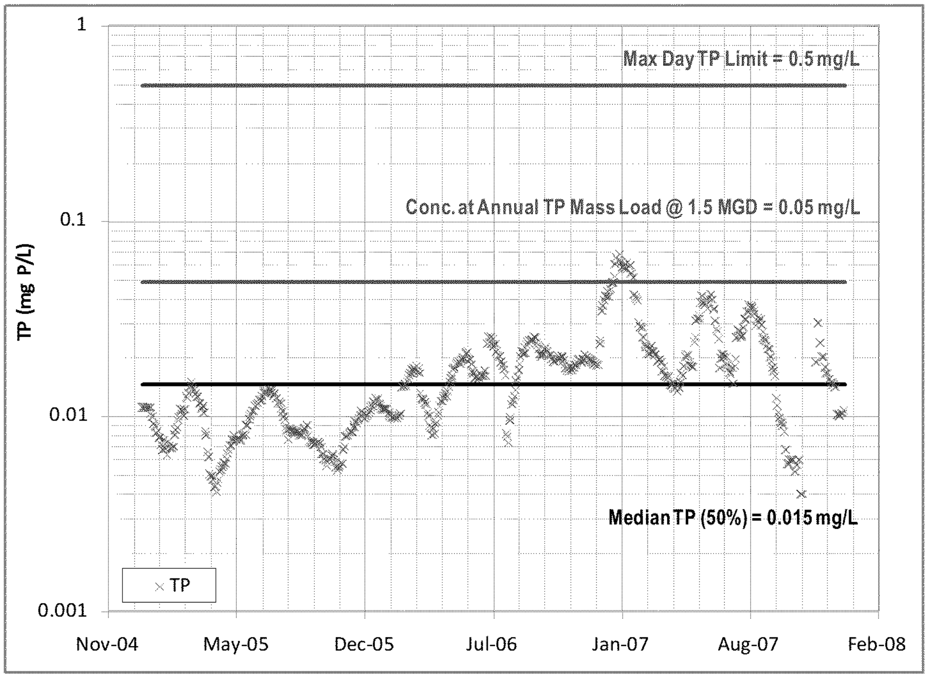

Figure 5-1. 30-Day Rolling Average Time Series Plot for the Iowa Hill WRF.

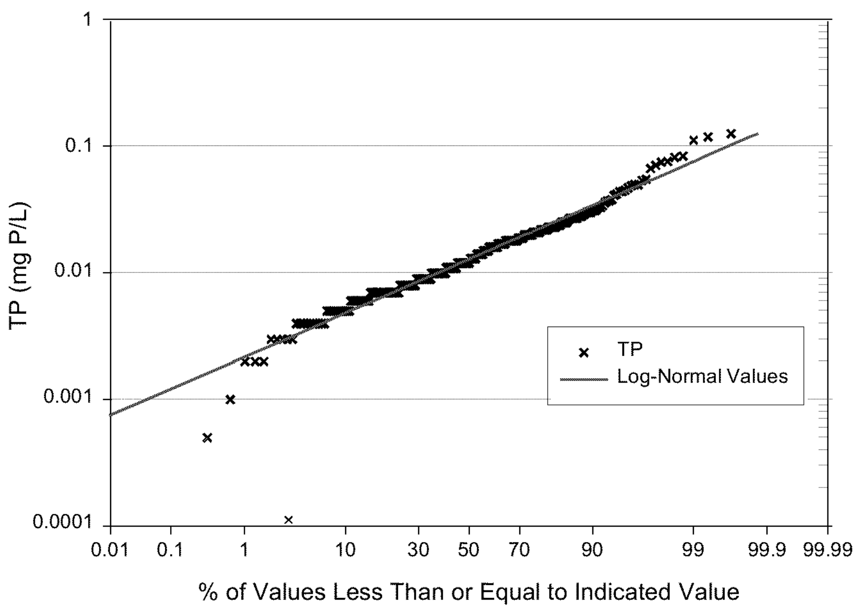

Figure 5-2. Daily Data Probability Plot for the Iowa Hill WRF.

5.4.2 F. Wayne Hill, GA

Data from January 2005 through December 2007 was reviewed for the F. Wayne Hill facility. Based on information provided by the plant manager, no major upsets that could have affected the statistical results were identified. Plant statistical information for the period from 2005 to 2007 is reported in Figure 5-3 and Figure 5-4.

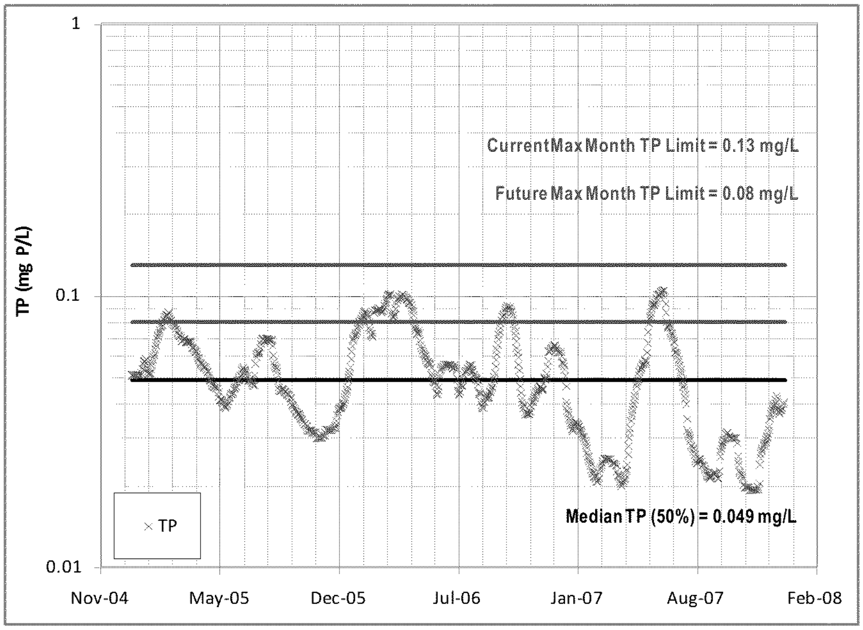

Figure 5-3. 30-Day Rolling Average Time Series Plot for the F. Wayne Hill WRC.

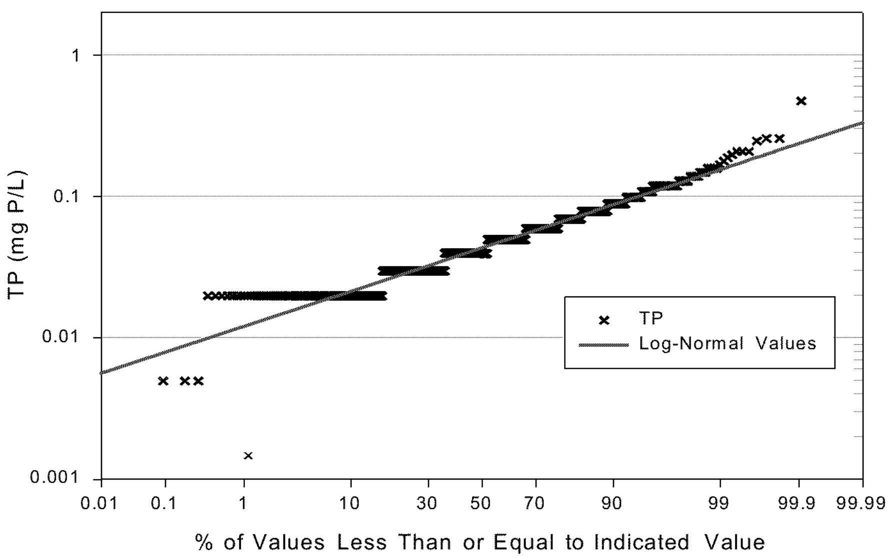

Figure 5-4. Daily Data Probability Plot for the F. Wayne Hill WRC.

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5.4.3 Cauley Creek, GA

Although no specific operational issues were identified by the plant manager, it was reported that influent flows and drought conditions had a large impact on the process. However, these could not be isolated with the available data. Another important parameter that affected the levels of P removal at the facility was related to the final use of the effluent produced at the facility. Drought conditions in Georgia favored the reuse of effluent rather than direct discharge. Therefore, higher effluent TP concentrations were allowed for reuse which lead to a reduction in overall O&M cost. Plant statistical information for the period from January 2005 to December 2007 is reported in Figure 5-5 and Figure 5-6.

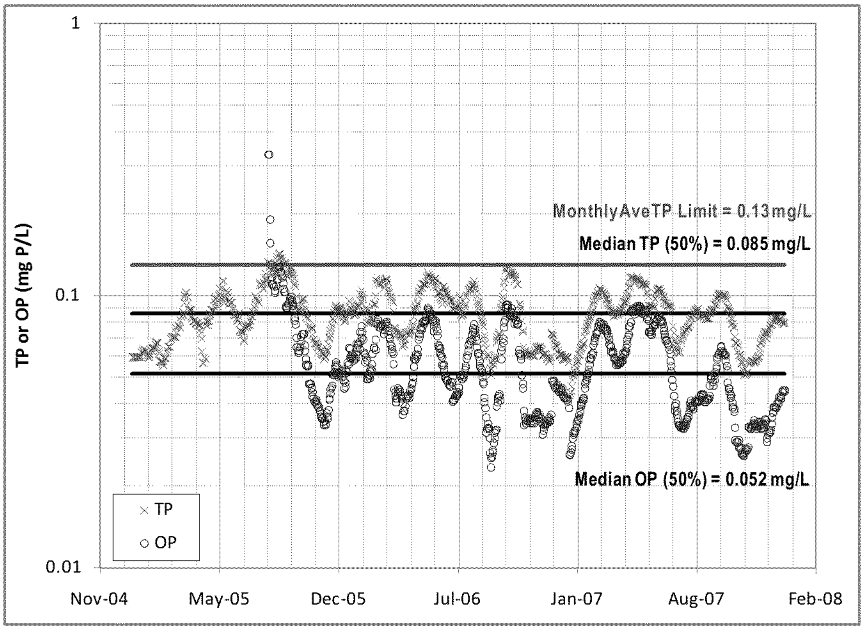

Figure 5-5. 30-Day Rolling Average Time Series Plot for the Cauley Creek WRF.

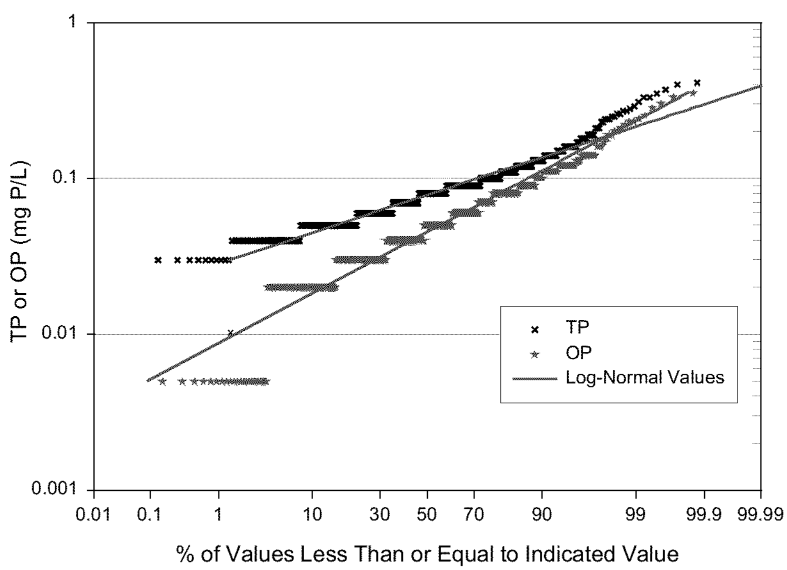

Figure 5-6. Daily Data Probability Plot for the Cauley Creek WRF.

5.4.4 Pinery, CO

During the January 2006 to December 2008 period, the Pinery plant experienced several challenges that affected the effluent quality of the facility including start-up of new facilities during the July-November 2007 period, optimization and adjustments of new units during the December 2007-July 2008 period and completion of reactor upgrades in August 2008. During the start-up and optimization process, no major impact on effluent quality was observed based on the data analysis. However, higher effluent TP concentrations were observed during the upgrade period of the reactors in August 2008 (or 2.7% of the time). If this period is not considered during the statistical analysis, the 30-day median value would change from 0.024 mg/L to 0.020 mg/L. During the reactor upgrade, a *Daphnia* bloom affected the effluent phosphorus levels; increasing the TP concentration from a median value of 0.023 mg/L to a maximum concentration of 0.10 mg/L. This event happened for a period of one week or 0.66% of the time. Plant statistical information for the period from 2006 to 2008 is reported in Figure 5-7 and Figure 5-8.

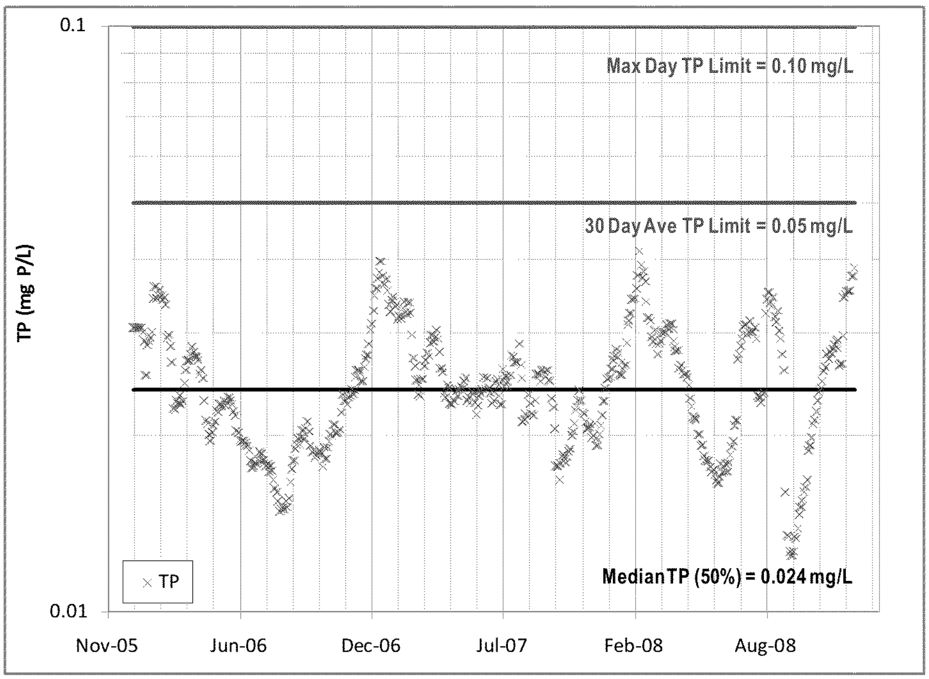

Figure 5-7. 30-Day Rolling Average Time Series Plot for the Pinery WWTP.

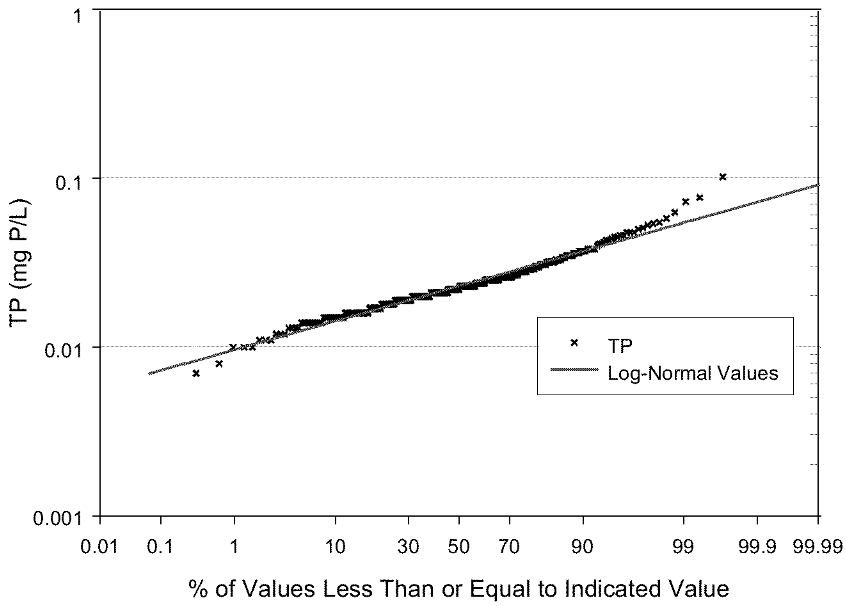

Figure 5-8. Daily Data Probability Plot for the Pinery WWTP.

5.4.5 Alexandria Sanitation Authority, VA

No process upsets were identified by the plant manager. Plant statistical information for the period from January 2005 to December 2007 is reported in Figure 5-9 and Figure 5-10.

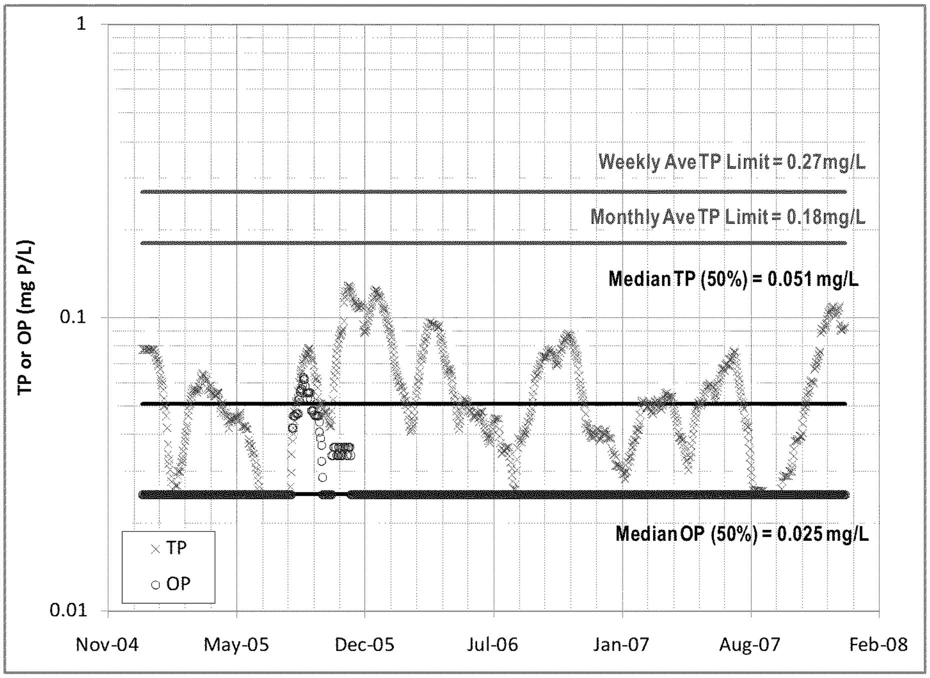

Figure 5-9. 30-Day Rolling Average Time Series Plot for the ASA AWTF.

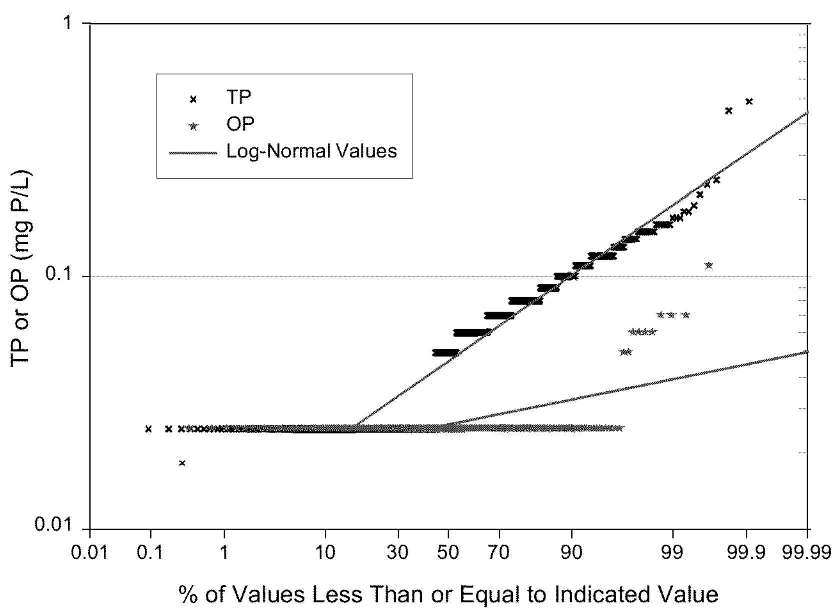

Figure 5-10. Daily Data Probability Plot for the ASA AWTF.

WERF

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5.4.6 Rock Creek, OR

The Rock Creek WWTP was analyzed from January 2005 to December 2007. However, because Rock Creek is not required to meet stringent limits during the wet seasons, the only data included in the analysis is for the dry months only. The transition between the wet and dry seasons can be observed in Figure 5-11 and Figure 5-12 as rapid increases or decreases in effluent TP and OP concentrations. No process upsets were identified by the plant manager.

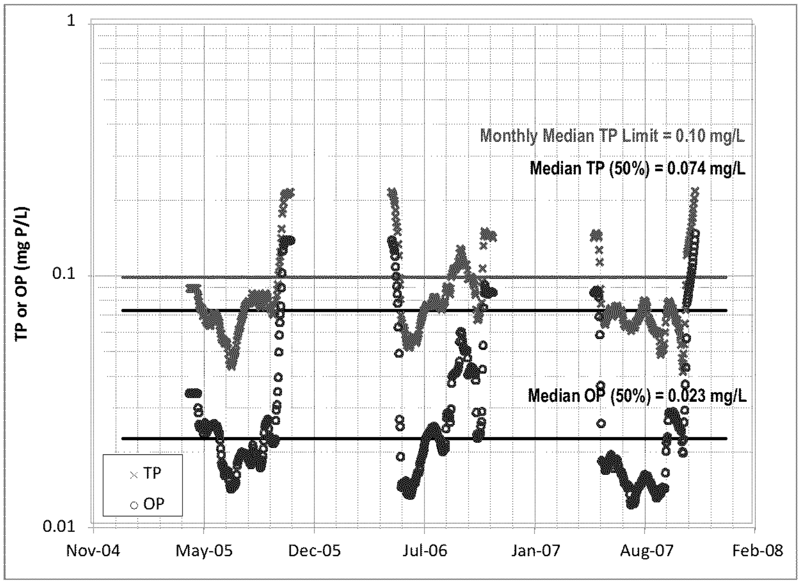

Figure 5-11. 30-Day Rolling Average (Dry Months Only) Time Series Plot for the Rock Creek AWTF.

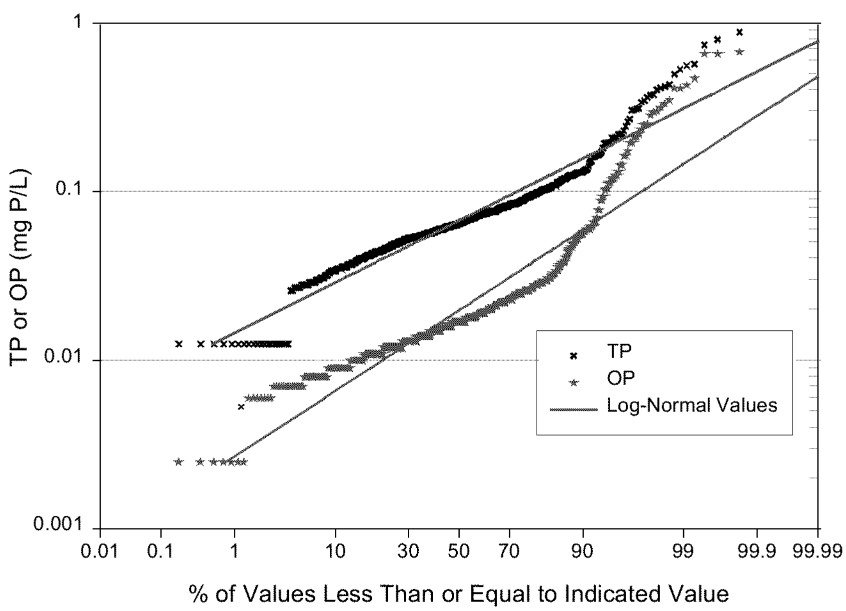

Figure 5-12. Daily Data (Dry Months Only) Probability Plot for the Rock Creek AWTF.

5.4.7 Blue Plains, DC

During the January 2005 through December 2007 period, the major operational upset reported by the plant manager was the chemical availability to maintain low phosphorus concentrations. In May 2005, the facility experienced a chemical supply interruption; therefore ferrous chloride dosing in the activated sludge process had to stop for a week (0.6% of the entire period). However, if this period is eliminated from the entire data set, the daily and 30-day median values would not change. Plant statistical information for the period from January 2005 to December 2007 is reported in Figure 5-13 and Figure 5-14.

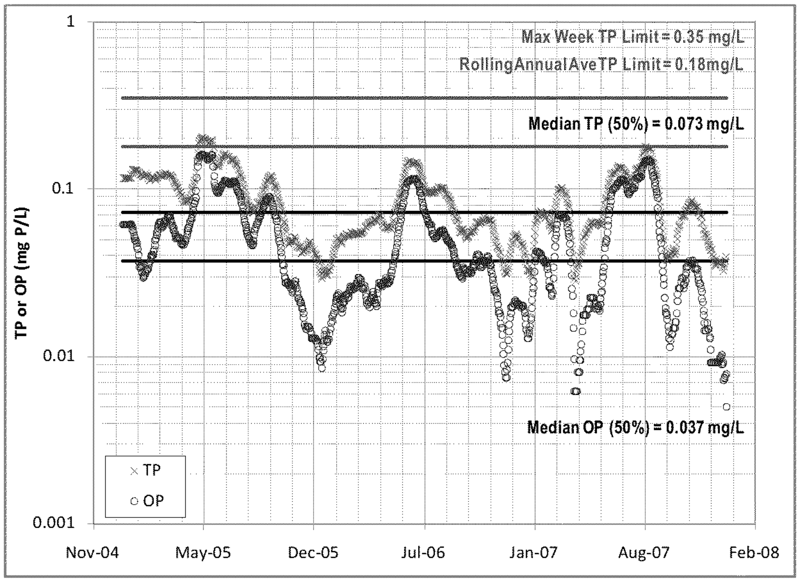

Figure 5-13. 30-Day Rolling Average Time Series Plot for the Blue Plains AWTP.

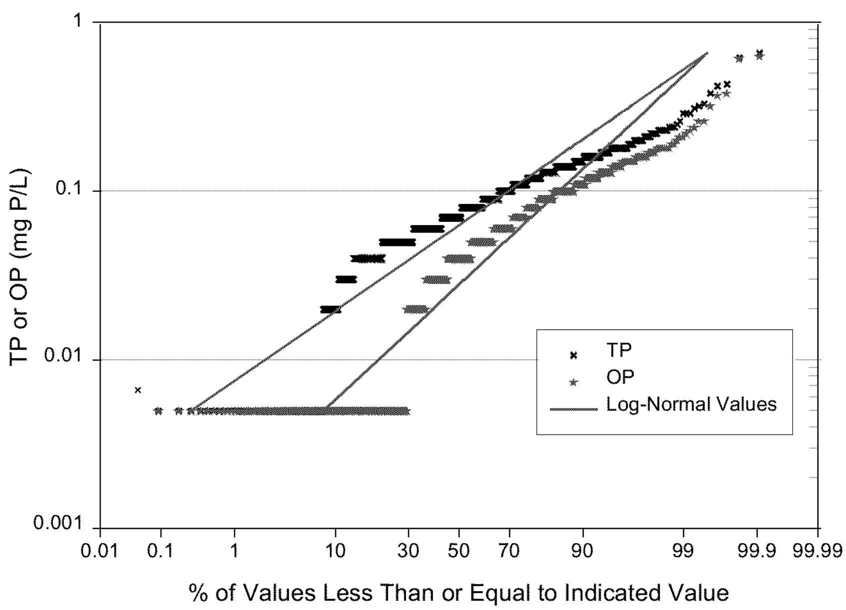

Figure 5-14. Daily Data Probability Plot for the Blue Plains AWTP.

WERF

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5.4.8 Kelowna, BC

Historical performance of the facility was evaluated from January 2005 through December 2007. During this period, two incidents were identified that led the facility to be out of compliance due to higher effluent TP concentrations. In July 2006, a single composite sample measured a TP concentration of 2.9 mg/L, exceeding the facility's not to exceed limit of 2.0 mg/L. However, the plant manager indicated that after investigation, no explanation was found for the higher effluent concentration. Following the July 2006 incident, in August 2006, a major plant upset was reported by the plant manager, which was believed to be related to a slug of heavy metals in the influent. This incident increased the effluent TP concentrations at the facility and lasted three days. Overall, based on the plant historical data, during the 2005-2007 period, four events (0.36% of the time) were identified that affected the effluent TP concentration at the facility. It should be noted that only some of these events can be related to a specific cause.

Based on the entire data set, the facility has effluent daily and 30-day median TP values of 0.15 mg/L (both for daily median and 30-day median values) with daily and 30-day maximum values of 4.1 mg/L and 1.2 mg/L, respectively. However, if the four events identified previously were eliminated from the data set, the overall daily and 30-day median and daily and 30-day maximum values would be approximately 0.15 mg/L (for both daily and 30-day median) and 0.60 mg/L (max daily) and 0.26 mg/L (max 30-day), respectively. Plant statistical information for the period from January 2005 to December 2007 is reported in Figure 5-15 and Figure 5-16.

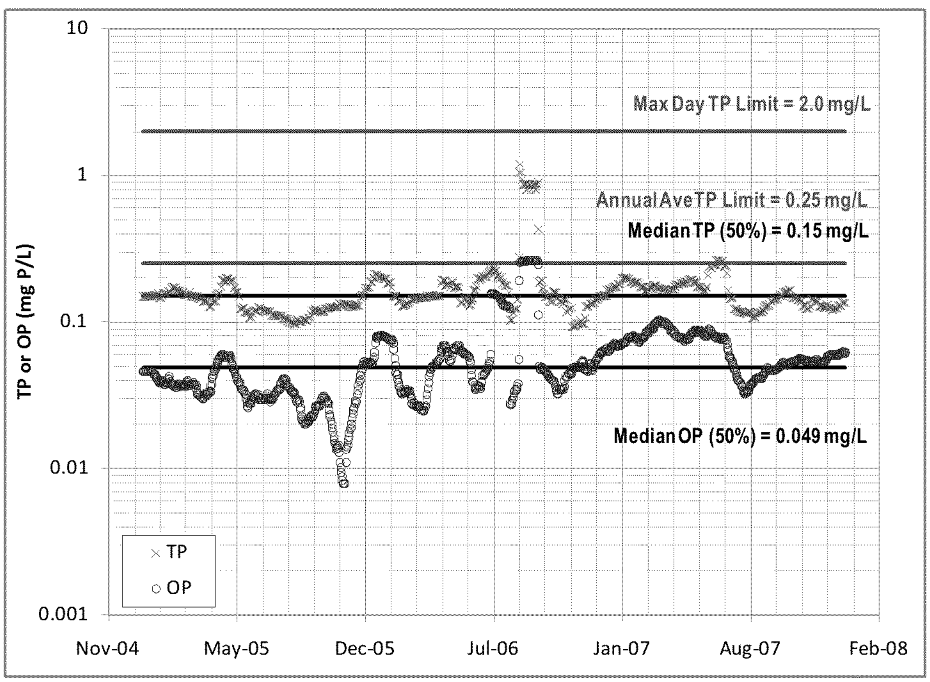

Figure 5-15. 30-Day Rolling Average Time Series Plot for the Kelowna WWTF.

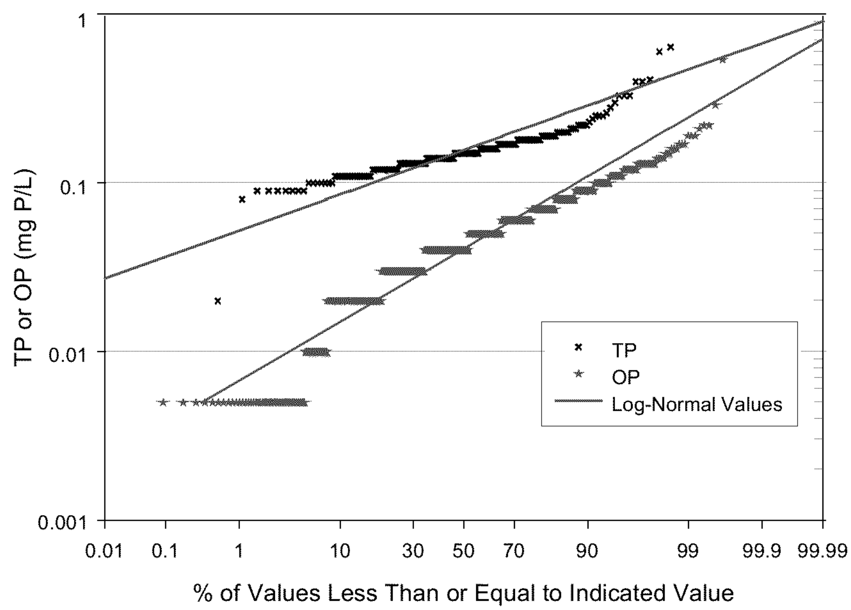

Figure 5-16. Daily Data Probability Plot for the Kelowna WWTF.

5.4.9 Kalispell, MT

There were several significant challenges for the Kalispell WWTP during the January 2005 to December 2007 period that affected normal operation and performance at the facility. In 2005, one secondary clarifier was taken out of service for major renovation. This project lasted three months (or 8.3% of the period being analyzed); however, the plant was able to maintain effluent TP levels low by adding aluminum sulfate to the process. Other issues reported by plant staff were related to environmental conditions such as high rain events and snow melt. However, these did not increase the final effluent phosphorus concentrations. Plant statistical information for the period from January 2005 to December 2007 is reported in Figure 5-17 and Figure 5-18.

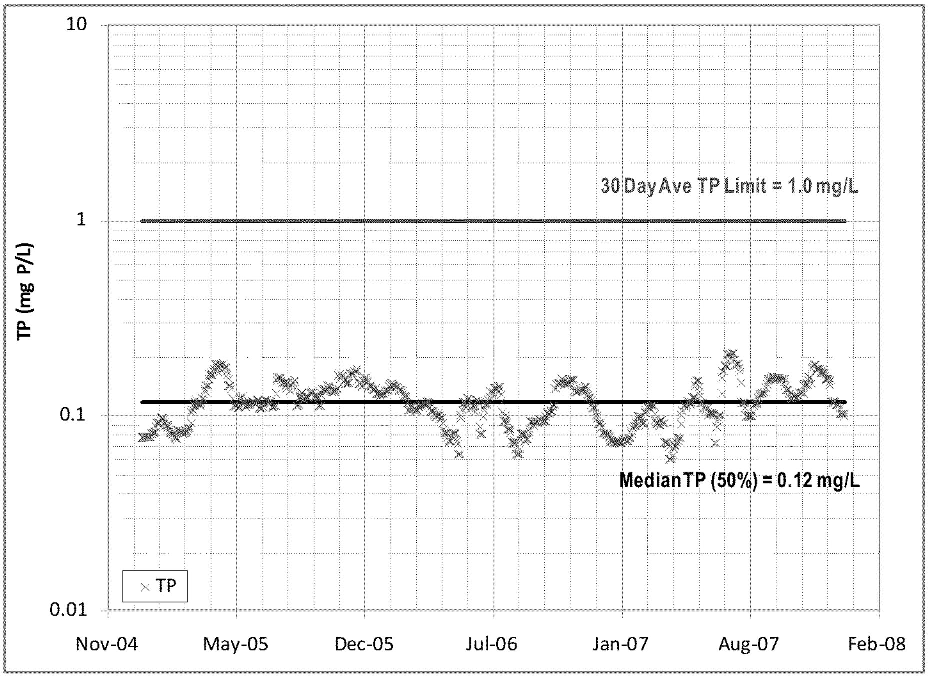

Figure 5-17. 30-Day Rolling Average Time Series Plot for the Kalispell WWTP.

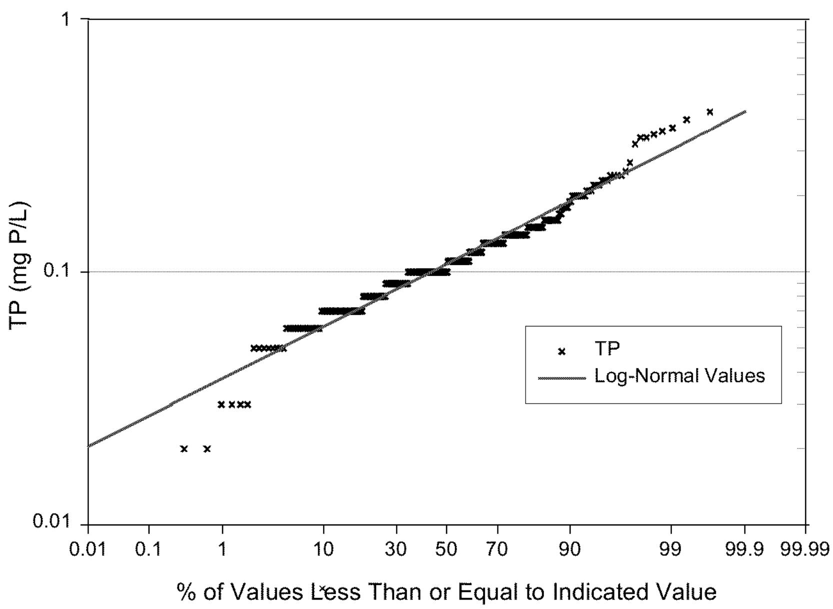

Figure 5-18. Daily Data Probability Plot for the Kalispell WWTP.

0007534

CHAPTER 6.0

NITRIFICATION RELIABILITY

6.1 Reliability

The daily data reliability values that were calculated for each plant are summarized in Table 6-1. The evaluation was done for all plants where ammonia removal information had been gathered including those that had been originally been included in the study to evaluate their nitrogen removal capabilities as well as three plants that were specifically added to evaluate their nitrification performance. The plant's permit limits for ammonia were not used in the evaluation either because some of the plants had no limits, while some had permitted ammonia-nitrogen limits that were higher than their TN limits (hence the latter controlled), or the ammonia limits were seasonally varying which overly complicated the comparison. Therefore the evaluation of reliability was based on the study selected objective ammonia concentration of 0.5 mg/L as N. The objective was used to calculate the ammonia reliability on a common basis for all of the plants that collected ammonia data. Note that the Tahoe-Truckee effluent values are for its BAF effluent and not its final effluent, which is measured after soil aquifer treatment.

Table 6-1. Summary of Daily Data Reliability Calculations for NH_3-N (Based on a Common Value of 0.50 mg/L).

Plant	Nitrification Process [a]/Flow Sheet Code [b]	NH_3-N Objective (mg/L)	NH_3-N Reliability (%)
Utoy Creek, GA	AS/1C_{Fe}-2B$C_{Fe}C_{Ac}$-3F	0.5	99.1
Fiesta Village, FL	AS/2C_{Al}-3C_{M}DF	0.5	97.4
Kalkaska, MI	AS/2BC_{Fe}	0.5	95.4
Western Branch, MD	AS/2$C_{M}C_{Al}$-3F	0.5	92.8
Truckee Meadows, NV	BR/1-2-3NTF-3C_{M}-3F	0.5	92.8
Tahoe-Truckee, CA	BR/1-3C_{L}-3C_{M}-3$_{CAl}$F	0.5	89.2
Parkway, MD	AS/1-2$_{CAl}$	0.5	84.6
Piscataway, MD	AS/1-2C_{Al}-3F	0.5	83.8
Scituate, MA	AS/2-3C_{M}DF	0.5	76.1
Kelowna, BC	AS/1-2$B_{CAl}C_{F}$-3F	0.5	73.1
Eastern WRF, FL	AS/2B_{CAl}-3F	0.5	57.2
Blue Plains, DC	AS/1C_{Fe}-2C_{Fe}-3C_{M}-3F	0.5	51.3
Littleton/Englewood, CO [c]	BR/1-2TF-3NTF	0.5	0.0

Note:
a. Process where nitrification takes place: AS = Activated Sludge, BR = Biofilm Reactor
b. See Chapter 3.0 for explanation.
c. Littleton/Englewood has ammonia based permits for which the lowest monthly permit value was 4.5 mg/L. The plant was not managed to achieve low ammonia values and operated to blend part of nitrified effluent with secondary effluent so as to achieve a combined chlorine residual.

An observation of the data in Table 6-1 demonstrates that all of the plants with ammonia permits were reliable when obtaining their specific permit limit. In terms of reliably achieving low effluent ammonia concentrations, the Utoy Creek plant outperformed all of the plants with an ammonia reliability of 99.1% at the ammonia objective of 0.5 mg/L. All of the plants, except for Scituate, EWRF, Kelowna, Blue Plains, and Littleton/Englewood achieved at least 80% reliability at the ammonia objective.

6.2 Technology Performance Statistics

Table 6-2 shows the daily data TPS ammonia concentrations calculated from all of the plants that were analyzed for nitrification reliability. The table also shows the type of process that was used to achieve nitrification. The results indicate that most of the technologies examined can on average accomplish a high degree of nitrification. However, the 95th percentile performance is highly variable, ranging between 1.6 and 53 times the median performance. This indicates that the nitrification performance variability is much greater than for nutrient removal performance.

Table 6-2. Ammonia Daily Data TPS Concentrations (mg/L) from Plants.

Plant	Nitrification Process [a]/Flow Sheet Code [b]	3.84% (14d)	50%	95%	3.84%/50%	95%/50%
Fiesta Village, FL	AS/2C_{Al}-3C_{M}DF	0.0050	0.0050	0.24	1.0	48.8
Kelowna, BC	AS/1-2$B_{CAl}C_{F}$-3F	0.010	0.30	1.16	0.033	3.88
Blue Plains, DC	AS/1C_{Fe}-2C_{Fe}-3C_{M}-3F	0.010	0.38	3.07	0.026	8.07
Western Branch, MD	AS/2$C_{M}C_{Al}$-3F	0.017	0.036	0.52	0.47	14.4
Piscataway, MD	AS/1-2C_{Al}-3F	0.017	0.017	3.24	1.0	191
Eastern WRF, FL	AS/2B_{CAl}-3F	0.020	0.10	5.25	0.20	52.5
Parkway, MD	AS/1-2$_{CAl}$	0.025	0.10	1.80	0.25	18.0
Utoy Creek, GA	AS/1C_{Fe}-2B$C_{Fe}C_{Ac}$-3F	0.030	0.040	0.14	0.75	3.50
Kalkaska, MI	AS/2BC_{Fe}	0.050	0.050	0.34	1.0	6.84
Truckee Meadows, NV	BR/1-2-3NTF-3C_{M}-3F	0.050	0.050	0.69	1.0	13.9
Tahoe-Truckee, CA	BR/1-3C_{L}-3C_{M}-3$_{CAl}$F	0.050	0.28	0.60	0.18	2.11
Scituate, MA	AS/2-3C_{M}DF	0.10	0.30	0.90	0.33	3.0
Littleton/Englewood, CO [c]	BR/1-2TF-3NTF	1.35	2.38	3.88	0.57	1.63

Note:
a. Process where nitrification takes place: AS = Activated Sludge, BR = Biofilm Reactor
b. See Chapter 3 for explanation.
c. Littleton/Englewood has ammonia based permits for which the lowest monthly permit value was 4.5 mg/L. The plant was not managed to achieve low ammonia values and operated to blend part of nitrified effluent with secondary effluent so as to achieve a combined chlorine residual.

Several of the daily data ammonia TPS-14d and TPS-50% values were restricted by the minimum detection limits of ammonia. Therefore, how the plants stratified may be directly related to each plant's particular MDL and not according to their actual performance.

Comparing the 95th percentile performance to the median performance shows that there is significant variability when attempting to achieve low levels of ammonia. Such wide ranges from the 3.84th percentile to the 95th percentile suggest that many of the plants experience loss of adequate nitrification.

6.3 Technology Evaluation

The main interest of the evaluation of nitrification capability was related to the ability of the various technologies to meet maximum day requirements, since as shown in Section 6.2, most technologies can accomplish a high degree of nitrification on an average basis. Very low permit concentrations for maximum day performance may be set for plants discharging to effluent dominated streams because of acute toxicity criteria. Thus, Table 6-3 focuses on peak daily performance and compares technology where activated sludge is used for the nitrification stage to technologies using biofilm reactors. The activated sludge technologies are shown in the upper part of the table, while the biofilm reactor technologies are shown in the lower part. Peak day performance in the 36 months of record for each plant is also compared to 99th percentile performance, to determine if there is anything unusual in the record which would alter the process rank. Recall, the 99th percentile performance would be exceeded 18 times in a five-year permit period if the effluent were to be analyzed every day. The process ranking is not altered much by the use of either statistic, with the Utoy Creek plant achieving the most dependable performance using either statistic.

Both the Truckee Meadows and Littleton Englewood plants are shown twice in Table 6-3, to show a comparison of the NTF effluent with the final effluent. The best performing activated sludge plants out-perform those with nitrifying trickling filters when comparing peak day performance statistics for ammonia.

Only four plants were identified that could meet a maximum day effluent ammonia criteria of 4.0 mg/L, meaning that reliability of plants with limits less than 4.0 mg/L will be expected to be poor. These plants covered a range of wastewater temperature conditions from warm to very cold. Other measures beyond what has been provided in the exemplary plants examined will have to be implemented to meet low maximum day ammonia limits.

On an annual basis, NTFs produce about 0.5 mg/L more ammonia nitrogen than the best performing activated sludge plants. However, when a nitrifying biofilm reactor is followed by a downstream denitrification reactor, ammonia uptake caused by biological growth in the denitrification step mitigates the difference. For instance, compare the results in Table 6-3 for the Truckee Meadows plant NTF effluent to the final effluent for the plant. The Truckee Meadows plant performance compares favorably to the best performing activated sludge plant effluents on an annual average basis. Similarly, compare the small difference between Tahoe-Truckee denitrifying BAF effluent to the Scituate and Fiesta Village plant effluents, both of which have denitrifying filters downstream of their nitrifying activated sludge step. And the nitrifying biofilm reactor plants that have a downstream denitrification step also have comparable statistics for maximum day statistics for the better performing activated sludge plants.

Table 6-3. Relevant Statistics for Effluent Ammonia Nitrogen Concentrations in the Study.

Plant	Nitrification Process [a]/Flow Sheet Code [b]	Maximum Day in Record, mg/L	Daily, 99th Percentile, mg/L	Annual, 50th Percentile, mg/L
Utoy Creek, GA	AS/1C_{Fe}-2B$C_{Fe}C_{Ac}$-3F	2.20	0.50	0.057
Scituate, MA	AS/2-3C_MDF	5.80	1.39	0.39
Fiesta Village, FL	AS/2C_{Al}-3C_MDF	3.11	1.68	0.042
Kelowna, BC	AS/1-2$B_{CAl}C_F$-3F	2.74	1.68	0.39
Kalkaska, MI	AS/2BC_{Fe}	4.24	1.82	0.12
Parkway, MD	AS/1-2_{CAl}	6.80	4.36	0.30
Blue Plains, DC	AS/1C_{Fe}-2C_{Fe}-3C_M-3F	6.74	4.58	0.82
Western Branch, MD	AS/2$C_M C_{Al}$-3F	9.49	4.65	0.17
Piscataway, MD	AS/1-2C_{Al}-3F	10.3	6.15	0.12
Eastern WRF, FL	AS/2B_{CAl}-3F	19.8	12.5	1.15
Tahoe-Truckee, CA, BAFs	BR/1-3C_L-3C_M-3_{CAl}F	2.53	0.83	0.28
Truckee Meadows, NV, Final	BR/1-2-3NTF-3C_M-3F	5.26	1.67	0.16
Truckee Meadows, NV, NTF	BR/1-2-3NTF	6.94	3.54	0.63
Littleton/Englewood, CO, Final [c]	BR/1-2TF-3NTF	7.71	4.72	2.48
Littleton/Englewood, CO, NTF	BR/1-2TF-3NTF	5.77	3.39	0.70

Note:
a. Process where nitrification takes place: AS = Activated Sludge, BR = Biofilm Reactor
b. See Chapter 3.0 for explanation.
c. Littleton/Englewood has ammonia based permits for which the lowest monthly permit value was 4.5 mg/L. The plant was not managed to achieve low ammonia values and operated to blend part of nitrified effluent with secondary effluent so as to achieve a combined chlorine residual.

6.4 Detailed Analysis of Nitrification Reliability Plant Performance

The following sections list the 30-day rolling average time series plots and daily data probability plots for all of the nitrification reliability plants except for the Kalkaska CWP since this plant was previously covered in Chapter 3.0. Each plant manager provided their insight on any data nuances or upsets in order to better understand what was occurring at each plant during periods of elevated effluent ammonia. General observations of the data are also provided for each plant.

6.4.1 Littleton/Englewood, CO

Data from January 2002 through December 2004 was analyzed. During this period, the performance of the facility was affected by two main issues: seasonal temperature variation and centrate management. Based on information presented by the plant manager, there were 91 instances where the NTF effluent daily ammonia values were higher than 1.0 mg/L. Of those events, 87 occurrences (or 7.9% of the entire period) coincided with the days when there was centrate tank drainage. Based on the entire data set, the facility has an NTF effluent median ammonia concentration of 0.46 mg/L based on the daily values. However, if the 87 events identified previously were eliminated from the data set, the overall daily median value would be approximately 0.40 mg/L. It should be noted that a construction project was completed in 2009 that included a centrate management system at the facility. Plant statistical information for the period from January 2002 to December 2004 is reported in Figure 6-1 and Figure 6-2.

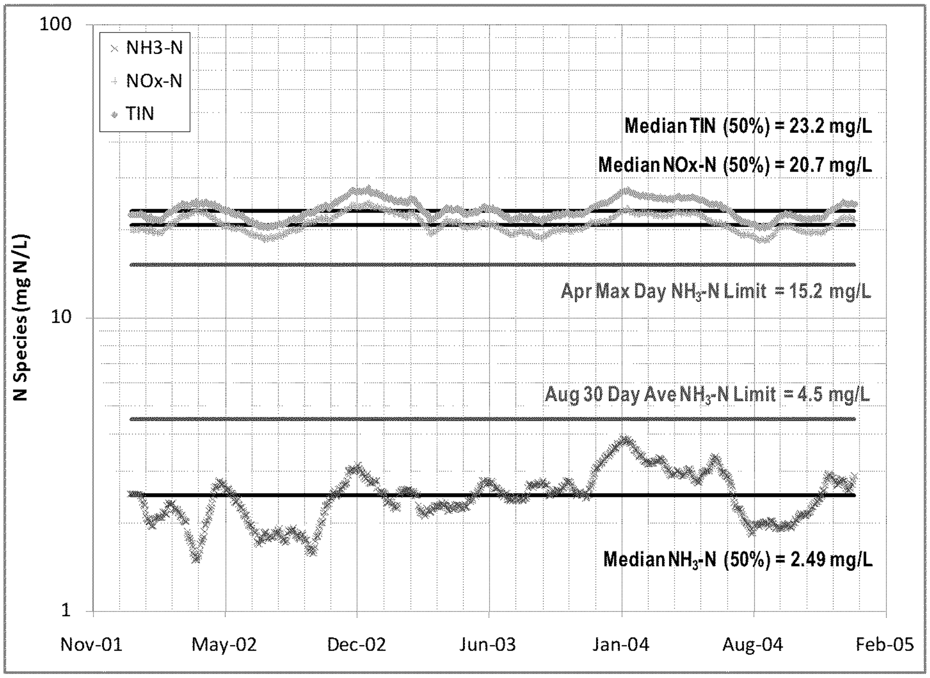

Figure 6-1. 30-Day Rolling Average Time Series Plot for the Littleton/Englewood WWTP.

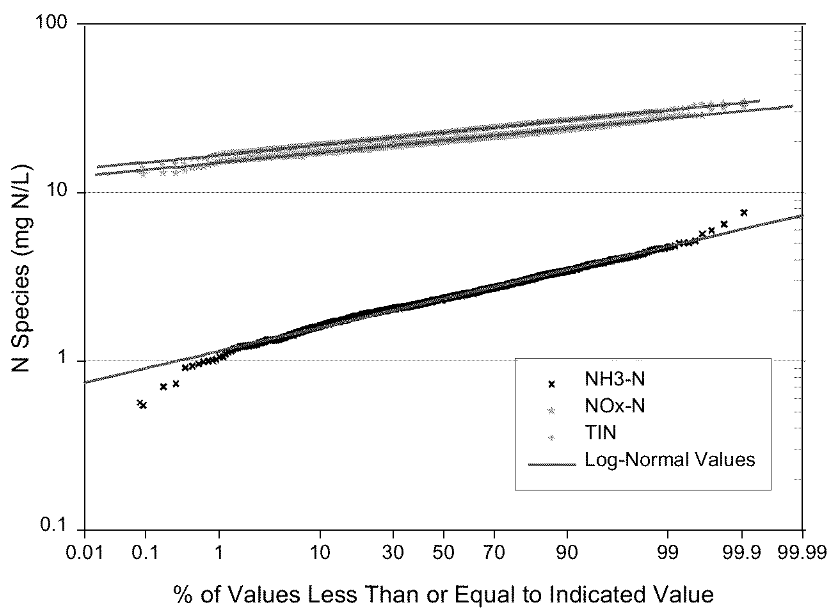

Figure 6-2. Daily Data Probability Plot for the Littleton/Englewood WWTP.

6.4.2 Utoy Creek, GA

Data from January 2005 through December 2007 was analyzed. No process upsets were identified by the plant manager. Plant statistical information for the period from January 2005 to December 2007 is reported in Figure 6-3 and Figure 6-4.

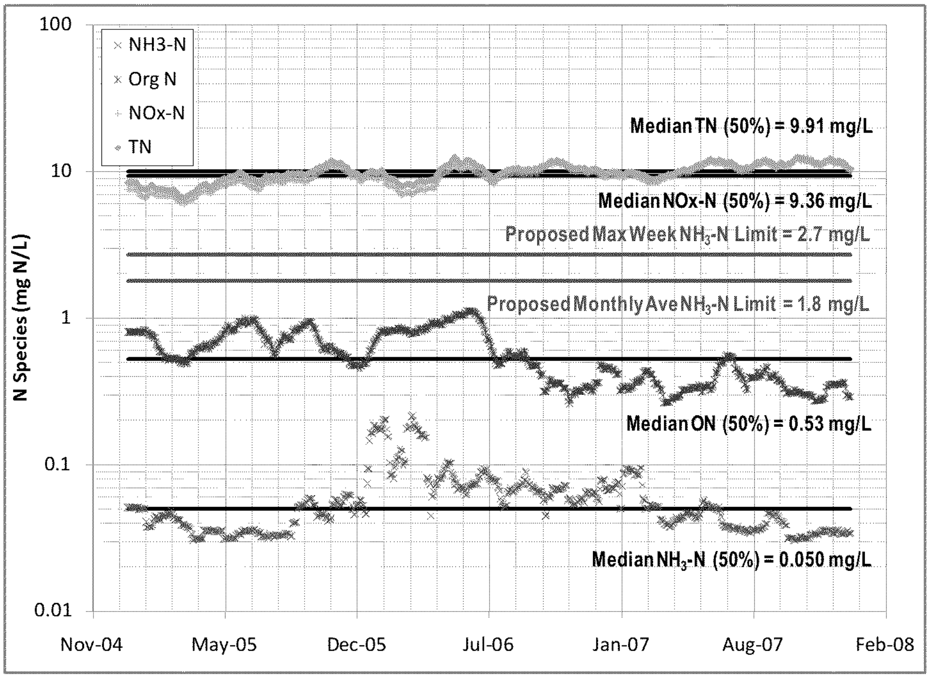

Figure 6-3. 30-Day Rolling Average Time Series for the Utoy Creek WRC.

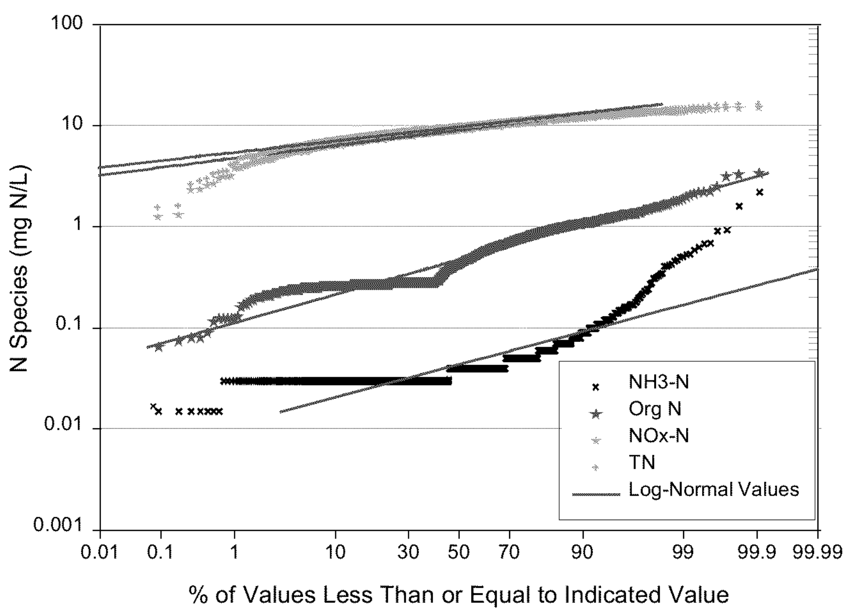

Figure 6-4. Daily Data Probability Plot for the Utoy Creek WRC.

CHAPTER 7.0

DISCUSSION

7.1 Lessons Learned from the Plant Managers

From a review of the 22 plants examined during this study, there were a few common things that can be concluded about maintaining low effluent limits. These are subdivided into external influences and design and operations factors.

7.1.1 External Influences

Infrequent toxic events upset two of the plants surveyed to varying degrees (Kelowna and Truckee Meadows Water Reclamation Facility). Biological processes are a main feature of all the plants surveyed and are subject to upset; while much as has been done to regulate toxic discharges to municipal plants, such programs are not oriented to completely preventing all such influences. This study was typically limited to 36 months of data, and it may well be that inclusion of longer periods of data for each plant might have shown that more of the facilities would have been impacted by such events.

The majority of plants in the survey use chemicals for either nitrogen removal or phosphorus removal. An unexpected interruption in chemical supply was cited by two of the plants as a potential or actual cause of effluent compliance issues (Blue Plains and Western Branch). The best a municipal agency can do is contract with reputable suppliers of chemicals. When these suppliers do not keep their commitments, then plants have experienced some process performance issues. With the increasing introduction of more stringent effluent requirements, the municipal wastewater industry will have an increasing need for chemicals and may see increased frequency of interruptions in supply if the market does not smoothly adjust to that increased demand.

Three of the plants (Pinery, Eastern Water Reclamation Facility, and Clark County) had plant upgrading projects underway and the impacts of that construction on their effluent reliability could be isolated. This can be expected to continue to occur as plants are upgraded or expanded.

Two of the plants indicated that peak flow events were there most difficult operating issue (Scituate and Fiesta Village). Similarly, the Iowa Hill manager identified seasonal variations in flows and loads as one of the more difficult issues facing his plant.

7.1.2 Operations or Design Influences

Three of the plants had biological treatment capacity issues and their performance was impacted in more stressed periods (Piscataway, Parkway, and Eastern Water Reclamation Facility). This accentuates the need for the regulatory authorities to provide for reasonable periods for planning, design and construction of plant upgrades so that online available capacity is sufficient to meet needs.

Two of the plants particularly (Pinery, Scituate) highlighted the advantage of having reliable online analyzers for process control (adjustment of chemical dosages) and had very positive experiences with them.

Two of the plants were negatively impacted by internal streams of ammonia containing sludge supernatant returns (Kalkaska, Littleton/Englewood) on nitrification performance, but each undertook operational or design changes to mitigate their impact.

Two plants were particularly satisfied with their flowsheets in terms of ease of operation (Western Branch and River Oaks). Similarly, the Fiesta Village manager identified the two stages of nitrogen removal in his facility as a principal reason for success in his plant.

The provision of storage for equalization or capture of off spec effluent was cited as a main advantage of the F. Wayne Hill plant by its plant manager.

Chemical feed control issues for phosphorus removal were identified in three of the plants as one of their more difficult operational control problems because of upstream process variability (Rock Creek), chemical feed sensitivity (Iowa Hill) or difficulties in pH control (Cauley Creek). One plant manager representing Clark County reported chemical feed control reliability as key to plant reliability for phosphorus removal.

One of the plants (Clark County) experimented with operational optimization trials that influenced its performance. The long term value of such experimentation in terms of minimizing costs while meeting stringent effluent requirements should be recognized and accounted for by regulatory agencies.

Fermenter control issues, while dealt with generally with success, were still the most difficult aspect of operations of in plants reliant solely on biological phosphorus removal (Kalispell, Kelowna).

7.2 Permit Setting Impacts

It was a common statement during the workshops that, since the plants were designed and operated to meet specific permit requirements, the performance statistics may not represent the absolute lowest value obtainable for the particular nutrient in question. While there is no doubt about this point, there is also no way to properly evaluate its impact from the existing data sets. By design, the project team studied plants with very low effluent limits and plants that were generally performing well; who is to say if even lower limits were set what the reliability of the plants under those new conditions would be? From the results of this investigation, all that can be said is that reliability would very likely decline with even lower limits.

Data or performance values from this study should not be directly transferred to other facilities for the purposes of establishing permit limits for new plants or ones without extensive databases. It should be recognized that no two plants treat precisely the same wastewater (both wastewater characteristics and flows and loads) or operate under precisely the same climatic conditions or treatment technologies. For example, some plants may have greater amounts of non-biodegradable dissolved organic nitrogen (nbDON) in their influent than others (Bratby et al., 2007, Pehlivanoglu-Mantas et al., 2008, Stensel et al., 2008), meaning that ability for that plant to reliably achieve the same limits will be more difficult than for plants with lower nbDON levels. Similar issues arise relative to phosphorus speciation (Neethling et al., 2007, Scherrenberg et al., 2008). Also, these parameters can change with time, such as an increase in concentration because of public response to water conservation programs.

Owners and plant designers have significant discussions and decisions to make in the future about levels of risk to assume in plant designs, as clearly when designing to approach "zero" there is no design that is risk free. This is in contrast with secondary treatment plant designs, when statistical methods could be used to show activated sludge plants would be stable if they were designed to produce mean values for SS of 10 to 12 mg/L and mean values for BOD_5 of 13 to 15 mg/l (Niku and Schroeder, 1981). Practical experience has shown designing for reliable secondary treatment has resulted in reliable designs without hardly any violations. So this "no violation" or "no risk" mental framework needs careful reexamination.

For example, let's say the monthly permit limit for a theoretical example plant is 0.2 mg/L. One of the plants in our study could achieve this 92% of the time. The 92th percentile statistic has sometimes been used to define performance in technology reviews (e.g. Kang et al., 2008). This means that the reliability to meet 0.2 mg/L is 92%. This may appear satisfactory (to some) or not (to others). To put this into perspective, 92% reliability means or 8% of the time there is an exceedance or in a 60-month permit period that would mean 0.08 x (60) = 4.8 months. This means that the plant will exceed the permit nearly every year!

Figure 7-1 shows the relationship between reliability and excursion frequency. From this figure it becomes clear that the reliability desired has to be very high in order to avoid exceedances. To be below one exceedance in five years requires over 98% reliability, a value so high it would likely increase capital and operating costs significantly. A 95% reliability will still potentially lead to three exceedances in five years, but the cost would be reduced. Agency tolerance for risk and willingness to deal with all of its consequences, including costs will be necessary elements of decision making in designing and operating plants that must meet stringent limits.

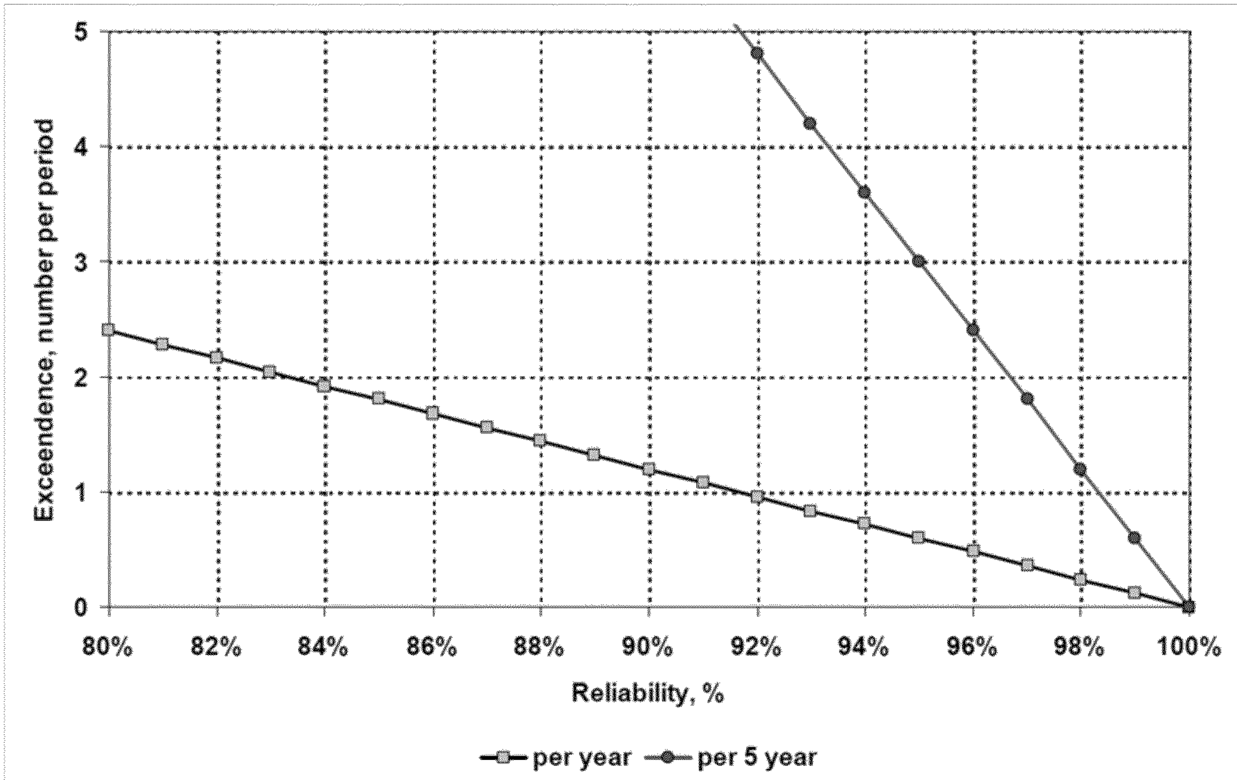

Figure 7-1. Relationship Between Reliability and Exceedances of Monthly Permit Values.

The permit writer also has a very influential impact on wastewater treatment plant costs when nutrient concentrations are set at very low levels. Because cost was either not reported or not reported on a consistent basis, this study did not feature comparisons of costs. Some of the cost data are presented in the treatment plant presentations. Cost of operation and cost of construction as well as measures of sustainability obviously factor into decision making about treatment process selection as well as the limitations of the treatment technologies for specific project conditions. The EPA survey (Kang et al., 2008) dealt with this difficultly in extracting real cost information by estimating instead the cost of new construction using a cost model rather than relying on plant specific cost information. Given the limited resources available for our study, this approach was not available to us. Based on experience, we would expect that as effluent nutrient concentrations become more stringent, costs would increase, with potential countervailing impacts on other environmental measures specific to sustainability. Moreover, the various flow sheets would likely differ in these parameters. These issues are best addressed on a watershed or individual plant level so as specific wastewater and receiving water conditions can be addressed and realistic costs can be developed.

CHAPTER 8.0

CONCLUSIONS

As with the previous Florida survey (Jimenez et al., 2007), the nutrient removal and nitrification plant flow sheets stratified themselves on a technology basis (see Table 4-4, Table 5-3, and Table 6-3). The combined nitrogen removal technologies could not be demonstrated to meet a maximum month nitrogen removal capability of 3.0 mg/L consistently. Relatively few of the plants have been built in colder Northern climates and judgment about this class will have to be postponed until new plants come on-line. As a class, single stage chemical addition processes for TP removal outperformed multiple stage processes in terms of achieving a 95th percentile maximum month concentration of 0.1 mg/L. There were plants in both the single and multiple stage chemical addition class that could meet the 0.1 mg/L annual basis (using the 90th percentile statistic). Achieving reliably low maximum daily permit values for ammonia is a significant problem for our industry; only four plants were identified that could achieve a maximum daily permit value for ammonia nitrogen of 4 mg/L. Rational permit writing that is oriented to achieving very low effluent limits for nutrients should be reflective of the limitations of treatment technologies as demonstrated by real performance of the exemplary plants that are currently achieving very low concentrations. The reality is that limits can be set that statistically guarantee exceedances rather than ensure compliance (for instance inappropriately set daily maximum or monthly maximum values). On the other hand, the data from this study conclusively show that using longer averaging periods are more likely to result in achievable limits as well as provide meaningful regulatory compliance triggers for many situations.

A simple statistical technique can be used to analyze treatment plant data to determine the reliability of nutrient removal process performance. Using percentiles calculated from final effluent data, the performance of the process and its associated reliability and variability can be quantified. TPS values representing the ideal performance (TPS-14d), median TPS (50%), and reliable TPS (typically 95th percentile based on either daily or monthly data) values provide plant owners, plant designers and regulators a tool to determine the ability of a technology or process to meet permit limits under consideration.

Using the data reported by full scale facilities, the investigation showed that:

- The operating conditions and specific conditions under which the data were collected impacts the TPS values. Permit or target treatment goals, external factors such as wet weather or industrial discharges, and internal factors such a construction impacts the variability of the results. All data should be included in the analysis. If special circumstances exist to exclude some data, the exclusions should be clearly stated.
- Flow sheets have been identified that have achieved either a monthly max of 3.0 mg/L TN or 0.1 mg/L TP on a 95th percentile basis. It is important to recognize that performance at this level for both TN and TP at the same plant has not been demonstrated.

- Separate stage N removal plants outperform combined N removal plants seemingly due to a higher degree of denitrification control possible with a separate stage process.
- Four- or five-stage Bardenpho plants come close to meeting the monthly TN goal of 3.0 mg/l, 95% of the time; a prior survey of 10 plants in a warm climate (Florida) show a capability of 3.5 mg/L. The exemplary performance of the cold climate Kalkaska plant, even though it only monitors TIN, shows that it may reach close to 3.0 mg/L TN on 95th percentile monthly basis, when assuming a range of values for its (unmeasured) ON content.
- As a class, single-stage chemical addition processes for TP removal outperformed multiple-stage processes, but often at the expense of higher chemical dosages.
- Tertiary chemical addition and effective filtration (gravity media or membrane) is required to achieve very low P. Plants with some form of tertiary chemical addition, clarification, and filtration outperform (slightly) those which have only effluent filters.
- The status of performance with MBRs for either N or P removal cannot be resolved (limited plants with three years of data).
- Kelowna and Kalispell (single stage BioP plants) performed very well without chemicals except where needed under unusual circumstances. This represents a tremendous achievement in terms of weaning plants from chemicals.
- Full scale plant performance for total nitrogen showed that the TPS-14d value of a typical plant is 50-60% of the median value. The TPS-95% is 180-250% of the median value. This clearly demonstrates the substantial variability in effluent quality even for a selection of the best performing nutrient removal plants in the U.S.
- Full scale plant performance for total phosphorus showed that the TPS-14d value of a typical plant is 40-50% of the median value. The TPS-95% is 200-300% of the median value. Again, a significant degree of variability in performance was observed.
- For total nitrogen and total phosphorus, comparing the 95th percentile to the TPS-14d, there is up to 10 times difference in these values for the plants operating at very low effluent concentrations. This substantial degree of variability in these exemplary plants should be recognized in the permitting and design process and is an important finding of this project.
- 95th percentile values for maximum month performance should not be the basis of regulation, since they represent three months of permit exceedance in a five-year permit period. For several plants, the maximum month value was significantly higher than the 95th percentile value and no consistent relationship between the two statistics was found.
- Only four plants were identified that could meet a maximum daily effluent ammonia limit of 4.0 mg/L, meaning that reliability of plants with limits less than 4.0 mg/L will be expected to be poor. Other measures beyond what has been provided in the exemplary plants examined will have to be implemented to meet low maximum daily ammonia limits.

It is clear from this work that calculating the probability or reliability of achieving a given permit limit is useful. If the data reasonably follow a log-normal distribution, these calculations are relatively straightforward and can be accomplished in a standard spreadsheet package. If not, it is a relatively trivial matter to calculate probabilities (percentiles from the data) and to develop log-transformed probability plots from which the reliability of complying with a given treatment objective can be determined. Equally useful is evaluating process performance under an appropriate set of averaging conditions (e.g., daily data, 30-day rolling average, annual average) at a selection of probability values that have important meaning with respect to permit compliance (e.g., 50, 91.8, 95%). This concept immediately lends itself to employing a statistical basis for permitting as well as defining the limitations of a treatment technology or process and the Technology Performance Statistics. In fact, Meyer et al. (2008) noted that this statistical evaluation of the Fiesta Village treatment facility was used productively in negotiation with regulators attempting to determine whether a more stringent permit could be imposed.

A major finding of the WEF/WERF investigation was that statistical variability is a characteristic of all the exemplary plants and that this variability should be recognized in both evaluation of technologies (e.g., stratifying them in terms of their capabilities) in an engineering environment as well as determining the appropriate effluent limits in the regulatory permit setting environment.

Although water quality protection must be the focus of point source nutrient permitting efforts, nearly all discharge permits applied to treatment plants in the U.S. require near 100% reliability; the consequence of not achieving this level of reliability is a permit exceedance. Based on this study of 22 plants approaching very low effluent concentrations, deterministic permit limits may not be appropriate for plants achieving very low nutrient limits, particularly when the limit is based on technology (concentration) rather than water quality-based (load). In addition, long averaging periods (i.e., annual average) are warranted given the inherent increase in variability of processes that must remove N and P species to concentrations approaching zero.

Local conditions impact the performance achieved on average and in terms of statistical variability. These factors include process design, climate impacts, wet weather flow influences, attributes of the service area, variation in influent flows and loadings, presence or absence of industrial contributions, whether solids processing is accomplished on the same site, sustained or interrupted supplies of chemicals, construction impacts, mechanical failures, the difficulty in operating the process, the ability to automate the controls of a process, the closeness of operation to design flows and loadings, and others. This makes it inadvisable to directly translate either the average performance or the statistical variability directly from a known plant situation to another location where there is no supporting database (for example, for a plant converting from secondary treatment to nitrification or nitrogen removal).

No clear relationship between flow and loading and performance could be deduced, except for clearly overloaded plants, such as EWRF. However, it should be expected that performance would suffer at a plant that is continually overloaded. River Oaks and ASA were overloaded on some parameters but were amongst the best performers in the study. There are many factors that impact this, such as the conservatism built into the design. Most of the plants in this study were under loaded with respect to flow and load.

Despite the various factors influencing performance from site to site, four plants out of the 22 plants analyzed in this study have been identified as the best performing plants with respect to nitrogen removal when evaluated on a maximum month basis. These are the Fiesta Village, River Oaks, Truckee Meadows and the Western Branch plants. Their 95th percentile monthly performance varied only from 2.2 to 2.5 mg/L. Considering all the factors influencing their performance, they cannot be further be distinguished in a technology stratification sense, one from the other. Their superior performance has one thing in common: they have either a separate denitrification stage or a polishing step with methanol, which allows more precise control of effluent quality than the processes with combined flow sheets (like Bardenpho) offer. This is not to say that any plant with one of the flow sheets these four plants represent can be placed anywhere, under any climatic and flow and loading condition and be expected to produce the same result. The four plants exhibit significant effluent TN variability in Technology Performance Statistics (concentrations and performance ratios), as documented in this report.

As another example, this investigation has shown that at low effluent TN levels, the composition of the TN becomes dominated by organic nitrogen (ON) that is resistant to further biological degradation. The ON residual is known to have significant plant to plant variability and is impacted by industrial contributions specific to each plant, ON in the drinking water supply as well as by extracellular production of ON by the biological organisms in the wastewater treatment process. Understanding the composition of ON and designing processes that can effectively remove it is a research need, if even lower effluent TN levels are sought beyond the capabilities of the technologies examined in this investigation.

It is the obligation of the regulators, regulated community, and the design engineering profession to recognize the process variability and higher risks that are attendant with the design for very low nitrogen and phosphorus concentrations or very low maximum day ammonia concentrations. When designing for typical secondary treatment requirements, high effluent concentration days can be balanced against low effluent concentration days. When designing for concentrations close to zero, it would require negative concentrations (which do not exist) to provide similar risk mitigation as occurred in the past with conventional secondary treatment. With current technologies, when designing or operating for very low levels, it is possible for regulators to permit concentrations that will automatically result in effluent violations no matter how much effort and cost is expended. The goal for regulators, operator and plant designers should be to assure the public that the investment of public dollars can properly be done by finding statistical bases for regulation that are both protective of the environment and are technologically achievable.

Considerable judgment must be employed in using this information in designing for Greenfield plants or conversions of secondary processes to nutrient removal, as the database herein can only be used for guidance and cannot be directly be translated. In design, highly parameterized plant process models are routinely used. When designing for effluents close to zero, these models do not accurately capture the statistical variability of nutrient removal processes. For such situations there are many unknowns that are not resolvable early in project implementation and are only partially compensated by conservatism in design. In such cases, success will only be statistically defined in the first years of plant operation. The improvement of process models to incorporate reliability, variability, etc is currently being considered by IWA/ WEF Task Group on Uncertainty in Design and Operations, but much work remains (Belia et al., 2009).

This investigation was limited by the availability of exemplary performing plants that had been operating for at least 36 months. In future years, the technologies that were emerging at the time of writing will have come online and should be subject to evaluation. In addition, there were a very limited number of nitrogen removal plants operating in cold climates in either the combined or multiple stage configurations at the time of study. However, there are a number of these currently under construction and data will start to become available within four or five years. Other technologies, such as BAFs and MBRs configured for either low nutrient concentration or high degrees of nitrification will be coming online and can be used to extend the database assembled in this investigation. When these plants accumulate sufficient operating history, they should be subjected to analysis so as to expand the conclusions about technology stratification presented herein.

Many technical publications can be found in the literature making claims about the capabilities of specific technologies in reaching low nutrient concentrations. Unless supported by complete descriptions about plant operation and design along with statistical analysis of data from longer term operating periods, these claims should be viewed with a high degree of skepticism. As can be demonstrated by examination of almost any of the cases analyzed here in, presentation of performance data without stating its statistical characteristics is virtually meaningless. Indeed, this investigation establishes a new protocol that should be used for data presentation in the future, so that data between studies can be comprehensively compared on common bases.

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